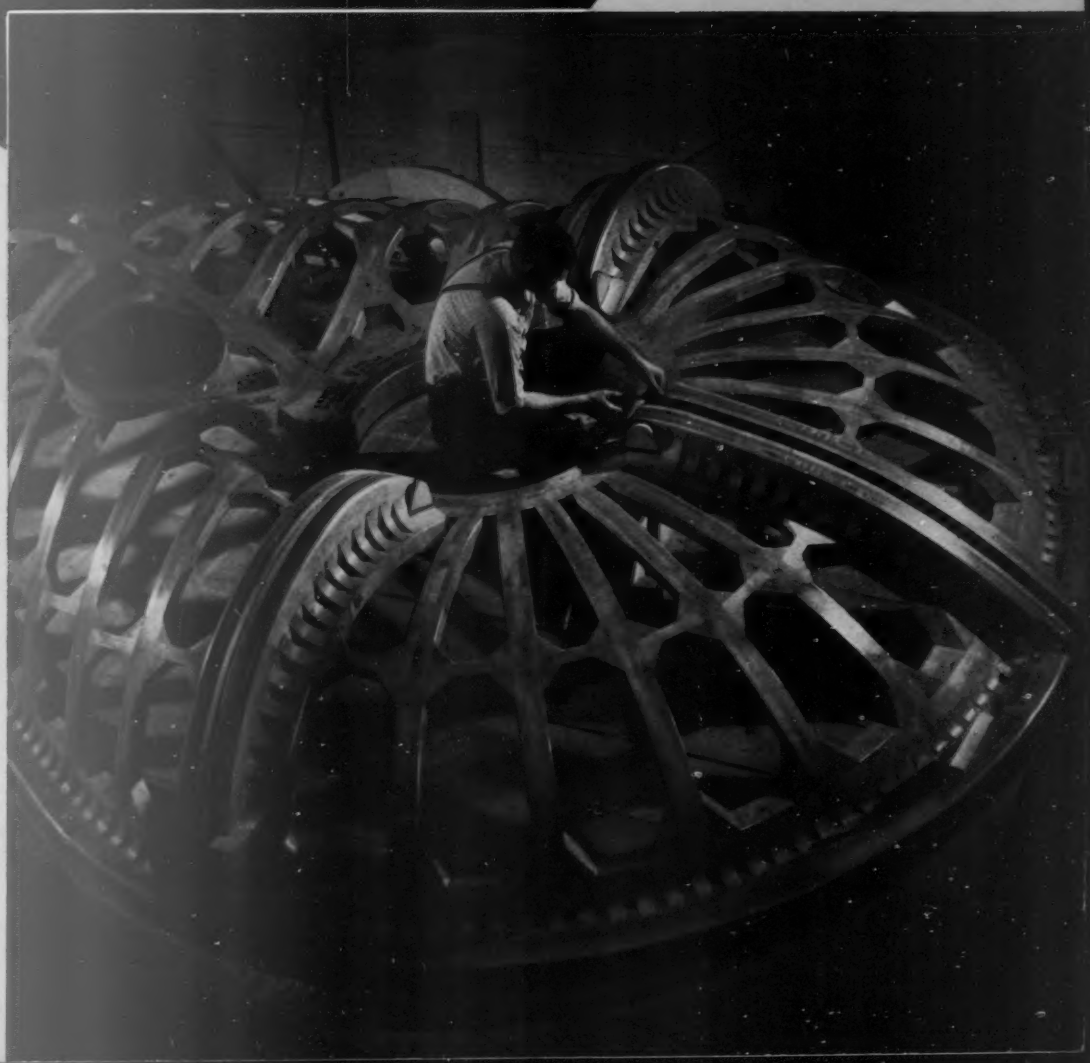
ALLIS-CHALMERS

ELECTRICAL REVIEW

S. B. Durand

March • 1942



Skeleton pattern for sweep molding the cast steel end bell of a hydrogen-cooled turbo-generator.

100%!

THAT'S THE CONTACT LIFE RECORD SET BY ALLIS-CHALMERS STEP REGULATORS

Regulating More Than 4,000,000 Kva in the Past Eight Years . . . One Answer to Better Regulation at Lower All-Around Costs!

Nearly a decade ago the first Allis-Chalmers 5/8% Step Regulator went into service. Today these modern feeder voltage regulators are delivering better regulation at lower all-around cost on 4,000,000 kva all over the country.

And, at the time this advertisement went to press, *not a single contact on an Allis-Chalmers Step Regulator had ever been replaced due to deterioration under normal operation!*

When the Allis-Chalmers engineers designed this regulator, the 5/8% steps . . . Half-Cycling operation . . . use of RS-1026 metal — all were incorporated to give you a mechanism capable of withstanding millions of operations over long years of actual service.

UNRETOUCHED PHOTOGRAPH of Allis-Chalmers Type AFR Regulator contacts after 2,000,000 tap changing operations. Note the lack of appreciable wear.

Now Allis-Chalmers offers you something different in three-phase regulators — unit type construction that *eliminates 78 bolted connections!* And there are no leads in air to absorb moisture.

Equally important, the Allis-Chalmers 5/8% Step Regulator is the only three-phase regulator with all voltage control relay adjustments conveniently located to save your operators' time and temper.

Bulletin B6056 gives complete engineering information on the Allis-Chalmers Type AFR 5/8% Step Regulator. Write for your copy...*today!*

A 1440

COMPLETING the assembly of a 12,000 volt, 208 kva Allis-Chalmers Type AFR 5/8% Step Regulator for a southeastern utility. Unit type construction eliminates 78 bolted connections.

ALLIS-CHALMERS

MILWAUKEE-WISCONSIN

These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost! Choose the Regulator to Fit Your Purpose!

DFR — 12 to 250 kva, single phase
AFR — 20.8 to 750 kva, three phase
CFR (air cooled) — 36-96 kva, 2400 volt, single phase

★

Vol. VII . . . . No. 1

March, 1942

Allis-Chalmers
Electrical Review

Board of Editors: R. S. Fleshiem, L. H. Hill, G. J. Callos. Executive Editor: D. S. Mortensen. Production Editor: F. C. Alexander. Associate Editors: R. Bell, O. Keller, H. Oman, L. Teplow. Photography: M. H. Zielke. Circulation: H. A. Reinhard.

Issued quarterly. Subscription rates: U. S., Mexico and Canada, $2.00 per year; other countries, $3.00. Address Allis-Chalmers Electrical Review, Milwaukee, Wisconsin.

Printed in U. S. A.
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Allis-Chalmers Mfg. Co.

ALLIS-CHALMERS

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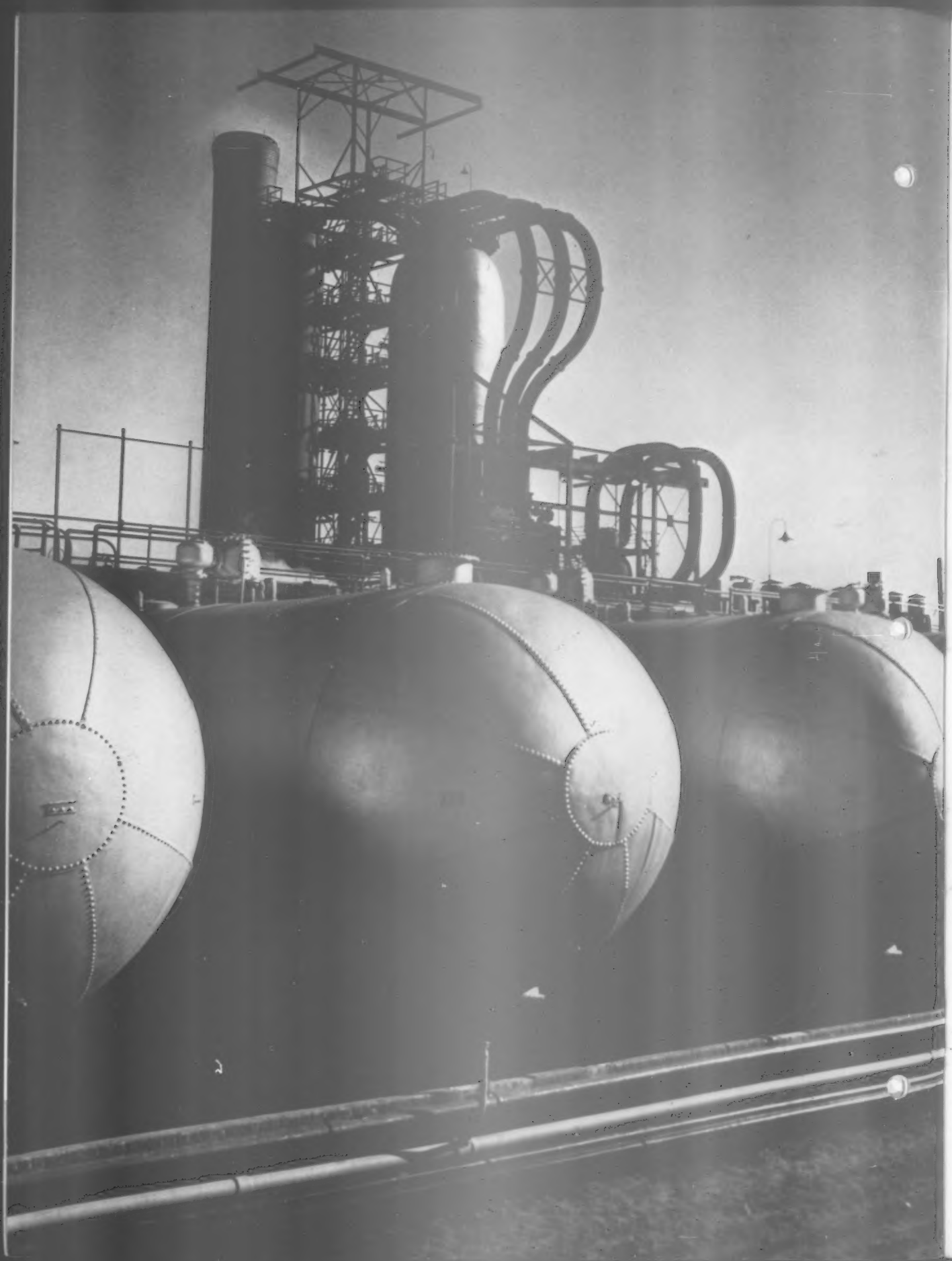


OIL FOR THE LAMPS OF AMERICA

America's lamps are electric, and the oil they use is to be found in the transformers and circuit breakers that distribute energy to them and to other units consuming electric power. Such oil must meet rigid specifications ... and does.

C. E. Trautman

GULF RESEARCH & DEVELOPMENT CO. • PITTSBURGH, PENNSYLVANIA

● After the birth of the electric power industry during the 1880's, efforts were directed toward finding materials which would act as dielectrics. Refined petroleum was discovered to have good dielectric properties, and it has been used almost from the start for liquid-immersed transformers and other liquid-filled electrical apparatus.

To the layman, oil generally brings to mind the thought of lubrication — making machinery run smoothly without friction or loss of power. By a stretch of the imagination, insulating oil may also be regarded as a lubricant. Its fundamental purpose is that of aiding the distribution of large amounts of electrical power with the least amount of friction and loss.

Actually, oil accomplishes this end by serving a twofold purpose in most oil-filled equipment: (1) it helps insulate electrically, and (2) it conducts away heat generated by electrical losses in the equipment. The relative importance of these two functions varies according to the type of apparatus and its actual design. For example, the oil in a transformer serves as an insulator and to prevent the core and windings from overheating; on the other hand, in certain types of high voltage underground cables the oil acts to a greater extent as an insulator, generally in connection with some form of paper insulation. This discussion is concerned with the manufacture and properties of the first type of oil — that used in transformers and circuit breakers.

Crude oil

Petroleum is made up almost entirely of compounds of carbon and hydrogen, although there are sometimes present small percentages of compounds containing sulfur, oxygen, or nitrogen. However, the ultimate carbon and hydrogen analysis of different crudes gives little indication of their widely different physical and chemical characteristics. The actual types of hydrocarbons and the relative quantities present primarily determine the physical and chemical properties of crude oil as it comes from the ground.

In general, the hydrocarbons of unchanged petroleum belong to the following series or classes of compounds: paraffins, naphthenes, and aromatics. The number of compounds possible in each series is very great. For example, in the paraffin series alone, it has been calculated that for a molecule of 25 carbon atoms and 52 hydrogen atoms (probably present in insulating oil), there are 36,797,588 combinations possible, each a different compound. Since compounds containing 40 or more carbon atoms may be present in some petroleum oils, the complexity of petroleum can be appreciated.

Without attempting to mention all the factors involved in selection of the proper crude, it may be said that past experience has shown that a so-called naphthenic crude (one which contains a relatively high proportion of naphthenic compounds), comparatively wax-free and low in sulfur compounds, will produce a highly satisfactory insulating oil.

Refining method

During the broad expansion of the petroleum industry, the refining of insulating oils as well as that of many other products of petroleum has been greatly improved. Since this summary is too limited to trace the historical development of refining processes, a typical modern method of refining insulating oil will be described. The sequence of the steps in refining is shown diagrammatically in the accompanying chart. Although it may not be apparent at first glance, the refining process is quite similar to a mass production assembly line method. This is undoubtedly the reason why the petroleum industry has been able to supply such a large quantity of highly purified material at low cost.

AT LEFT: In refining, crude oil is first separated into arbitrary fractions of various boiling point ranges in large fractionating towers like those shown in the background.

A miniature earthquake in the making. Sensitive seismograph instruments, located at various distances, record reflections of the "earthquake" sound waves from subsurface rock strata and assist the prospector in locating possible oil-containing structures.

Distillation

The first step in refining is a separation of the crude oil by distillation into arbitrary fractions of various boiling point ranges. Distillations are carried out in large fractionating towers, such as those shown on page 4. The usual major fractions are: gasoline, kerosene, gas oil, lubricating oil, and the undistilled portions called the residuum. These fractions are the starting materials for further refining to produce the many varied and useful products made from petroleum.

Other fractions may be taken, of course, and it is also possible to redistill the major fractions to obtain closer cuts. An insulating oil fraction may be regarded as a heavy gas oil or light lubricating oil distillate. A typical fraction has a viscosity of 50 Saybolt seconds at 100 F and a boiling point range of 475 F to 700 F. This fraction is the starting material for further chemical refining.

Chemical refining

The main object in chemical refining is the removal of the undesirable constituents which would cause instability if left in the finished oil. Sulfuric acid has long been successfully employed for this purpose although certain solvent methods have also been applied successfully to this type of oil.

The action of sulfuric acid on petroleum is complex. It is known that the more unstable hydrocarbons, particularly certain of the aromatic compounds, are attacked most readily by sulfuric acid. The acid also lowers the total sulfur content and removes resins and asphalt. The action of the acid can be regarded as removing first the most unstable compounds and then, progressively, the more stable compounds. However, oils can be overtreated with sulfuric acid. There is a definite degree of refinement beyond which the quality of an oil is no longer improved and may even be impaired. The quantity of acid to produce the most stable oil varies, depending on the properties of the starting stock; this optimum quantity of acid must be determined experimentally before refining can be started.

The actual treatment is accomplished by mixing the acid with the oil in a reaction tank for about 20 minutes at ambient temperature. A typical amount of acid employed in the treatment is 100 pounds per barrel of oil. The reaction products of the acid with aromatics, resins and asphalt settle to the bottom of the reactor, leaving the clear oil on top. The oil is separated from the acid sludge and neutralized. This is accomplished by agitating the oil with a water solution of caustic soda. Following neutralization, the oil is washed with water to remove excess caustic soda.

After chemical refining, the oil may require further distillation treatment to insure that only a narrow

A modern derrick, used in the drilling for oil beneath shallow water, rises against the sky.

Empirical Equation	Units	Calculated Values of Properties					
		d=0.865			d=0.895		
		0 F	60 F	180 F	0 F	60 F	180 F
1. Specific Heat $S=\frac{1}{\sqrt{d}}(0.388+0.00045t)$	Btu/lb/deg F	0.417	0.446	0.504	0.411	0.440	0.496
2. Coefficient of Expansion $C=A+2B(t-60)$ where $\log(A\times10^5)=0.835+\frac{0.70}{d}$ $\log(B\times10^8)=\frac{2.10}{d}-1.20$	/deg F	0.00042	0.00044	0.00048	0.00040	0.00042	0.00045
3. Thermal Conductivity $T=\frac{0.813}{d}[1-0.0003(t-32)]$	$\frac{\text{Btu}}{\text{ft}^2\text{hr deg F/in.}}$	0.949	0.930	0.908	0.917	0.899	0.876

In the above equations (in engineering units): d=specific gravity at 60/60 F t=temperature in deg F
From C. S. Cragoe, Bureau of Standards, Misc. Publication 97 (1929)

Table I — Thermal Properties of Petroleum Oils

fraction of the proper boiling point range and viscosity remains. This step is followed by filtration of the oil through absorptive clay to improve the color, to remove any solid particles and to reduce the water content of the oil.

The final step remaining to finish the oil is to dry it thoroughly. Each refiner usually has a preferred method for drying insulating oil. One typical method is to filter the oil through a blotting-paper filter press until the proper dielectric strength is obtained. After dehydration, every precaution must be taken to prevent the oil from picking up moisture. The tank cars used to transport the larger quantities to the consumer are generally equipped with breathers filled with a desiccant, such as calcium chloride.

Characteristics of the finished oil

The characteristics of the finished oil may vary to some degree, but the important properties are carefully controlled during manufacture. The following series of values will serve to illustrate tests on a typical insulating oil (all results based on standard ASTM tests):

Specific gravity, 60/60 F	0.8870
Viscosity, Saybolt sec at 100 F	54
Flash, deg F	275
Fire, deg F	310
Pour point, deg F	60
Carbon residue	Trace
Neutralization No.	0.01
Steam Emulsion No.	20
Dielectric strength, kv	30

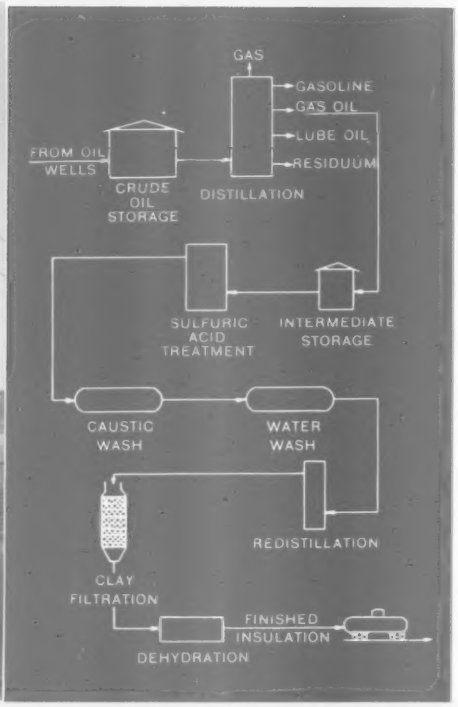
The actual composition of the oil, so far as classes of compounds are concerned, can be estimated by means of an empirical method. The following are typical results of a finished oil:

Aromatic rings, %	8
Naphthenic rings, %	43
Paraffins (including side chains), %	49

Since one of the main purposes of an insulating oil is to provide a cooling medium, the values of the thermal properties — namely, specific heat, coefficient of expansion and thermal conductivity — may be of interest. These values vary with the actual composition of an oil and also with the temperature. Experimental correlations of these values with physical properties of average oils are generally used to estimate values for other oils. It is usually assumed that the correlation of data, given by C. S. Cragoe at National Bureau of Standards (1929), can be used with confidence in engineering calculations. Table I shows Cragoe's empirical equations based on specific gravity and also shows values of the thermal properties calculated at several temperatures for two insulating oils representing a fairly large spread in specific gravity.

The important electrical property is dielectric strength As indicated by the typical value above, the dielectric strength of clean, dry oil is around 30 kv (ASTM test, 0.1 in. gap).

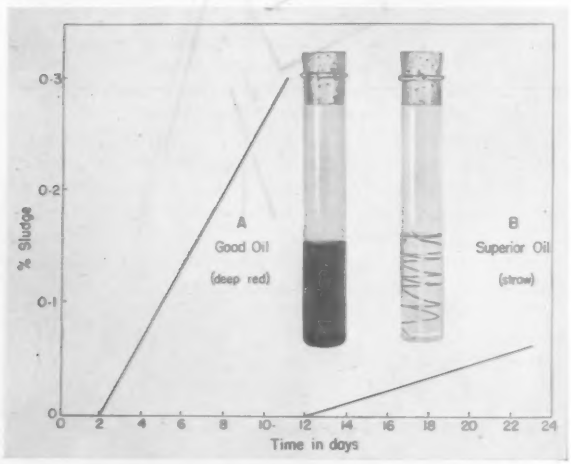
Completed well, with production by-passed, shows quantity of oil flowing from a typical well.



Sequence of steps in the modern refining of insulating oil.

The oil in service

Although insulating oils are relatively stable chemically, they may deteriorate under certain conditions in service. At elevated temperatures, oils may react with oxygen to form oxidation products such as organic peroxides and acids. Some of these compounds may polymerize to form oil-insoluble sludge. Sludge is undesirable in a transformer, for it may cover the immersed surfaces and prevent efficient heat transfer. This causes the transformer to operate at increasingly higher temperatures under the same load condition.



Transformer oils having identical initial conventional specifications as affected by accelerated oxidation tests.

Oxidation may also reduce the ability of the oil to resist emulsification with water. The presence of water in oil-filled electrical equipment is obviously dangerous because it reduces the dielectric strength of the liquid. Badly oxidized oil may also cause corrosion of metal parts or may attack insulation. The amount and rate of deterioration which may occur for a given oil is difficult to predict because of the wide variety of conditions met in service. Probably the most important factors in connection with oxidation in service are temperature of operation, availability of oxygen to the oil, and presence of catalysts, such as metals.

Unfortunately, it is not always possible to predict how an oil will perform under known service conditions by examination of its initial physical properties. That is, oils with the same initial physical properties may behave entirely differently under the same conditions of service, depending on the type of crude and the actual refining treatment. Empirical laboratory tests have been devised to evaluate the relative oxidation stability of the oils and to predict their subsequent behavior in service. In these tests the effects of the oxidizing influences involved in service are accelerated. By means of such tests, it is possible for the refiner to control the quality of an insulating oil by varying the amount and type of treatment involved in the manufacture of the oil. These tests also provide a basis for study and research to enable the refiner to improve constantly the quality of the oils.

"GIVE 'EM AIR!"

Burdened with today's vastly increased loads, power systems are being invigorated by the use of compressed air for circuit breaker operation. And on the "watchdogs" of our transmission lines, its properties of reliability and speed are proving vitally important.

G. E. Jansson and H. W. Martin

SWITCHGEAR DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

Compression and subsequent storage of air has long been recognized as an economical, flexible, and reliable method of storing energy. The uses to which compressed air is put are manifold. For example, the use of compressed air by railroads for braking, signalling, and for operation of main line switches dramatically proves its reliability under all kinds of weather and temperature conditions since the safety of millions of passengers is dependent upon its ability to function smoothly and without trouble. The wide use of compressed air in steel mills, paper mills, submarines, and commercial refrigeration also proves it to be an economical and satisfactory method of storing energy for future use. Compressed air is also quite commonly used in generating stations for various purposes such as cleaning.

Although the use of compressed air for circuit breaker operation and circuit interruption formed the subject of many early patents (Fig. 1) and some pneumatically-operated oil circuit breakers have been functioning satisfactorily for over 40 years (Fig. 2), compressed air has been rarely used in connection with circuit breakers. Electrical storage batteries have been the prevailing medium for storage of energy for circuit breaker operation.

The advent of air blast circuit breakers, coupled with increasing demands for high-speed operation of oil circuit breakers, has, however, recently caused a revival of interest in the use of compressed air as applied to circuit breaker operation. As a result, a number of installations of pneumatically closed oil circuit breakers have recently been made, in addition to air blast circuit breaker installations. Both air blast circuit breakers and pneumatically-operated oil circuit breakers have already been adequately described, [1, 2, 3] and the purpose of this article is to discuss the properties of compressed air in its application to circuit breaker operation.

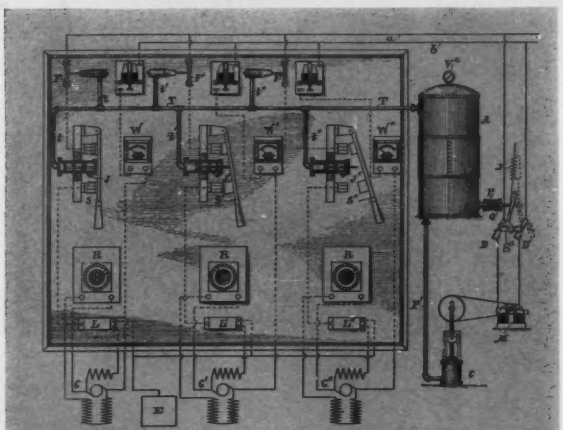


Fig. 1—Pneumatically-opened knife switch from a patent to Elihu Thompson, June 5, 1894.

Fig. 2 — Pneumatically operated oil circuit breaker, installed in 1899 at L St. station of Boston Edison, rated 1500 amp, 3000 volts. Operating pressure is 40-50 lb.

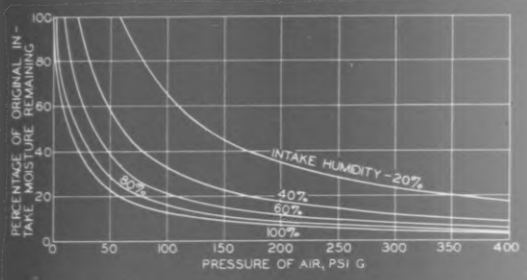


Fig. 3—Percentage humidity of original intake moisture remaining in saturated compressed air at original intake temp at various pressures.

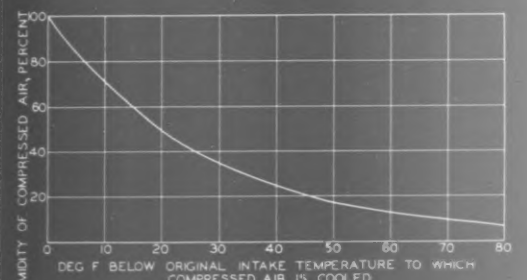


Fig. 4—Percentage humidity of compressed air at original intake temp for various degrees of after-cooling.

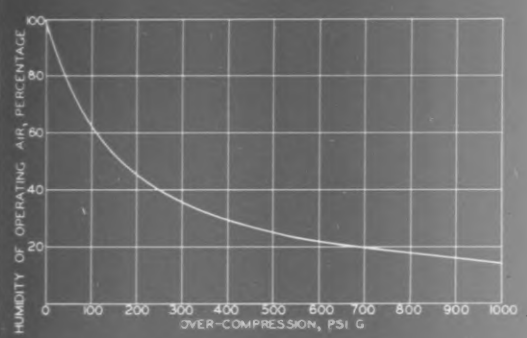


Fig. 5—Percentage humidity of operating air at 150 psi for various intake temp at various values of over-compression.

The problem of operating circuit breakers by means of compressed air differs little in general principles from that encountered in the pneumatic operation of other mechanical devices. Actuation of moving parts in correct sequence is easily obtainable at any desired speed by regulating the areas of cylinders and pistons and of the ducts leading to them. In addition, the degree of operating reliability and safety required may be considered as no greater than that for other generally accepted pneumatically operated devices previously mentioned.

As in other important pneumatically operated devices, precautions have to be taken to insure a constant supply of relatively clean air. Due to the availability of suitable non-corrosive materials, the presence of moisture is not considered detrimental for indoor operation. For outdoor operation (and, when desired, for indoor operation) suitable means are employed to insure air free from water deposits that might interfere with satisfactory operation of the circuit breaker.

Moisture Content

Practically all free air contains moisture in varying degrees, the measure of its moisture content being indicated by its humidity percentage. One hundred percent humidity is the point beyond which moisture will be separated out and deposited as water.

The capacity of air at a given temperature to hold moisture is inversely proportional to its absolute pressure. For instance, assume air at atmospheric pressure (14.7 psi abs) and having 100 percent humidity is compressed to 120 psi G, the air will be compressed $\frac{14.7+120}{14.7}=9.16$ times.

The theoretical humidity of the 120 lb G air will, therefore, be 100 percent $\times$ 9.16=916 percent. Assuming that the 120 lb air is at the same temperature as the original free air, 100 percent humidity would still be its maximum ability to carry moisture so that $\frac{916-100}{916}$ or 89.2 percent of the original moisture would be separated out of the 120 lb air and deposited as water in the sump of the 120 lb air container, leaving the tank full of saturated air.

Actually the air delivered by the compressor would be at a much higher temperature than that of the original free air (approximately 260 F for intake air at 60 F) due to the heat of compression; and, since the capacity of air to carry moisture approximately doubles for every 20 F increase in temperature, the high temperature air delivered to the 120 lb air container would have a low humidity although it would still carry all of the moisture taken in through the compressor intake.

As the air in the container cooled down to the original ambient temperature, however, its capacity to carry moisture would be reduced by half with every 20 F drop in temperature until finally the 120 lb air tank sump would contain 89.2 percent of the original moisture and the compressed air in the tank would be saturated (100 percent humidity). From then on, any increase in temperature would lower the humidity of the 120 lb compressed air, and any decrease in temperature would cause additional moisture to be deposited in the air tank sump.

It is interesting to note that, for any humidity index for the intake air above approximately 11 percent, the air in the 120 lb tank, at the original ambient temperature, would be saturated, the theoretical humidity under such conditions being 11$\times$9.16=100.76.

Since the average yearly humidity in different parts of the U. S. A. varies between 40 and 86 percent, it follows that compressed air at pressures used with circuit breakers (120 to 200 lb psi G) will invariably be saturated unless it is considered advisable to take steps to reduce its moisture content. It should be remembered, however, that the saturated air contains only a small percentage of the moisture contained in the original intake air, as will be seen from reference to Fig. 3.

Moisture Removal

Several economical methods, of varying efficiency, for removing moisture from compressed air are available. One of the most convenient is dependent upon the fact that every 20 F drop in temperature approximately halves the capacity of air to carry moisture. If, then, the air leaving the compressor is artificially cooled to below ambient temperature before it enters the air tank, the compressed air in the tank will then have something lower than 100 percent humidity. For instance, if air at 60 F is compressed to 120 psi G and cooled to 40 F before delivery to the air tank, the air in the tank will have a humidity of 50 percent at 60 F. This process can be accomplished by water cooling (passing the air through pipes surrounded by circulating water, or passing air over pipes through which cooling water is circulated) or by means of refrigeration. Fig 4 shows the reduction in humidity for various degrees of after-cooling.

Another convenient method of reducing the percentage humidity of the operating compressed air is to compress the air to a pressure considerably above the operating level, cool it to ambient temperature, and then pass it through a reducing valve into the operating air tank. Suppose, for instance, that air at 150 psi G is required for operation of air blast circuit breakers. Compression of the air to 375 lb G and subsequent cooling will probably remove 90 percent or more of the moisture originally taken in through the compressor, leaving saturated air at 375 lb G. Subsequent expansion of the air to 150 lb G will reduce the humidity of the air in proportion to the reduction in absolute pressure so that the humidity of the 150 lb air at the original ambient temperature will be

$$\frac{150+14.7}{375+14.7}\times 100 = 42.3\%$$

Fig. 5 shows the reduction in humidity of 150 psi G operating air for varying degrees of over-compression.

Moisture can also be removed from the compressed air by forcing it through an air drier containing a substance having a strong affinity for moisture, such as calcium chloride, sulphuric acid, phosphoric pentoxide, or activated alumina. Of these, probably the most acceptable is activated alumina, which is capable of absorbing almost 100 percent of the moisture and can absorb as high as 25 percent of its weight in water. The introduction of such a drier, however, increases maintenance since such driers become saturated and have to be reactivated.

It is obvious that a wide degree of moisture control is available by the use of any combination of the various moisture-reducing methods enumerated.

Operation of oil circuit breakers

Figure 6 is a piping diagram of a typical compressed air system for use with pneumatically-closed outdoor oil circuit breakers, described in detail in a previous issue.[3] The air storage tank is attached to the circuit breaker frame, and the remainder of the equipment is accommodated within the waterproof control cabinet, as indicated by the chain-dotted line in the figure. The air pressure in the tank is automatically maintained within fairly close limits by means of the pressure regulating switch, which starts the compressor motor at the lower pressure limit and stops the motor at the upper limit.

For indoor installation, air requirements are not so heavy; and, where frequency of operation is not so great, one air tank may serve for several breakers. It should be noted that compressed air is used for the closing operation only of oil circuit breakers. The latching and tripping details are the same for pneumatic operated breakers as for solenoid operated breakers.

It is usually considered satisfactory in applications of this kind to rely on the compression cycle as the principal means of moisture removal since, in the most severe case of intake air at 100 percent humidity, the

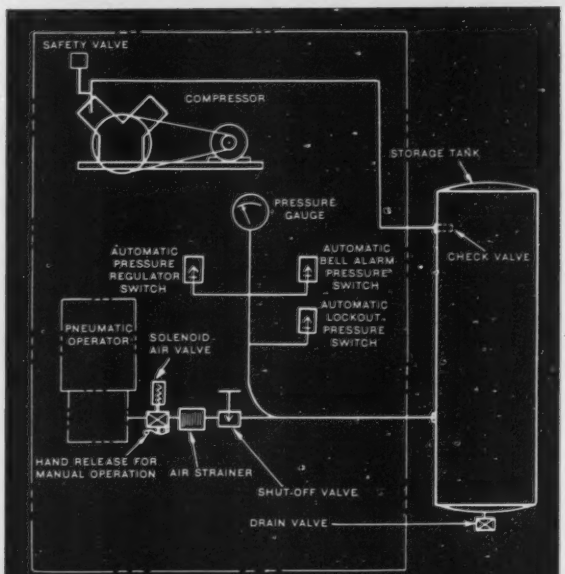


Fig. 6 — Piping diagram of air system for use with pneumatically-closed outdoor oil circuit breakers.

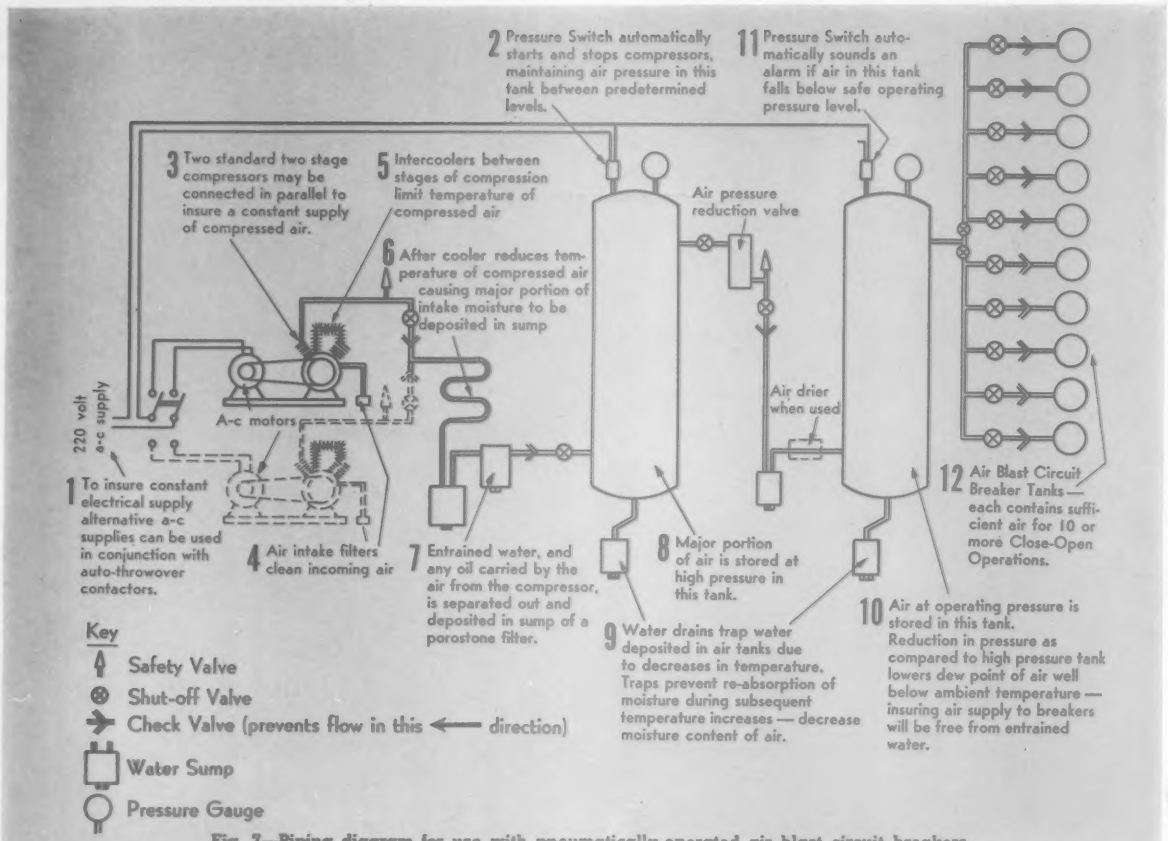

2 Pressure Switch automatically starts and stops compressors, maintaining air pressure in this tank between predetermined levels.
11 Pressure Switch automatically sounds an alarm if air in this tank falls below safe operating pressure level.
3 Two standard two stage compressors may be connected in parallel to insure a constant supply of compressed air.
5 Intercoolers between stages of compression limit temperature of compressed air
Air pressure reduction valve
6 After cooler reduces temperature of compressed air causing major portion of intake moisture to be deposited in sump
220 volt a-c supply
A-c motors
Air drier when used
12 Air Blast Circuit Breaker Tanks — each contains sufficient air for 10 or more Close-Open Operations.
1 To insure constant electrical supply alternative a-c supplies can be used in conjunction with auto-throwover contactors.
4 Air intake filters clean incoming air
7 Entrained water, and any oil carried by the air from the compressor, is separated out and deposited in sump of a porostone filter.
8 Major portion of air is stored at high pressure in this tank.
9 Water drains trap water deposited in air tanks due to decreases in temperature. Traps prevent re-absorption of moisture during subsequent temperature increases — decrease moisture content of air.
10 Air at operating pressure is stored in this tank. Reduction in pressure as compared to high pressure tank lowers dew point of air well below ambient temperature — insuring air supply to breakers will be free from entrained water.
Key
Safety Valve
Shut-off Valve
Check Valve (prevents flow in this ⟵ direction)
Water Sump
Pressure Gauge

Fig. 7—Piping diagram for use with pneumatically-operated air blast circuit breakers.

120 psi G air used would deposit over 89 percent of the original intake moisture in the bottom of the air tank when the air cools down to the intake temperature, as shown in Fig. 3. The stored air in the tank would be saturated, of course; but, if the temperature within the control cabinet is maintained higher than that of the air in the tank, there would be little danger of condensation in the operating part since during the closing operation the air is not permitted to expand to any large degree. This desirable temperature differential is easily and economically obtainable by the installation of a small heater at the bottom of the cabinet.

Where freezing temperatures are anticipated, a quantity of low viscosity motor vehicle anti-freeze solution can be put into the bottom of the air tank. It is intended that a certain amount of the anti-freeze solution will be carried by the air so that, when the air passes through the solenoid air valve, it will tend to prevent defective operation due to the occurrence of freezing temperatures within the control cabinet. This action would also apply to the operating air cylinder, though to a markedly less extent, because of the high degree of effort exerted by the operating compressed air.

As an additional precaution, an air strainer is installed in the pipe line ahead of the solenoid valve to prevent small particles of foreign matter that might interfere with its satisfactory operation from passing into the valve. The piping to the solenoid valve is also upgrade so that, should any moisture be deposited in this piping, it will flow away from the valve. Where low temperature conditions are expected to be severe, defective operation can be guarded against by the introduction of a simple over-compression and cooling stage between the compressor and the storage tank in order to reduce the humidity of the stored air. In addition, the temperature within the control cabinet can be automatically maintained above the freezing point by means of thermostatically controlled heaters. Alternatively, the solenoid valve can be equipped with its own heating elements.

Operation of air blast circuit breakers

A typical piping diagram of an air system for use with a large installation of indoor air blast circuit breakers is shown in Fig. 7. Because the functions of the air blast breaker are dependent on a constant supply of relatively clean air, it is here necessary to take every reasonable precaution to insure that the

supply of air will not fail. While the use of non-corrosive materials for fabrication of operating parts renders the breaker relatively unaffected by water deposits, it is considered desirable to remove as much moisture from the operating air as is economically justified.

Two electrically-driven compressors are used, connected in parallel to insure a constant supply of compressed air. An automatic pressure switch, connected to the high pressure air tank, controls the compressor motor and maintains the air pressure in the high pressure tank between fairly close limits. The air is over-compressed and, after leaving the compressor, passes through a simple after-cooler in order to reduce the air temperature to as near ambient temperature as possible, thereby squeezing out and depositing in the cooler sump the major portion of the moisture taken in through the compressors. After leaving the cooler, the high pressure air passes through an oil and water separator equipped with a porostone filter, for the purpose of filtering out any condensed water and any oil from the compressor which may be suspended in the air stream, and then passes through a check valve (which allows flow of air in one direction only) into the high pressure air tank, where the major portion of the air is stored so as to reduce the space occupied by the compressed air.

The air in the high pressure tank will, of course, be saturated, and any drop in temperature will lower the moisture carrying capacity of the air, causing water to be deposited in the bottom of the air tank. Any water deposited in this manner is drained off into a water trap so that it cannot be reabsorbed by the air when the temperature rises again. Consequently, recurring cycles of decreased and increased temperature will tend to lower the humidity of the air in the high pressure tank.

From the high pressure air tank the air is passed through a reducing valve into the operating air tank. Reduction of the air pressure to the operating level lowers the humidity of the air, the decrease in humidity being dependent upon the amount of over-compression, as shown in Fig. 5. The operating air tank is also equipped with a water trap so that, in the event of the temperature dropping far enough to cause the humidity of the air to increase to the point where water will be separated out of the air, the water will be drained off and trapped, resulting in further lowering of the humidity due to recurring decrease and increase in temperature.

From the operating air tank the low humidity compressed air passes through its individual check valves to the various air blast breaker air tanks. Since indoor ambient temperatures are not subject to wide variations, it is safe to assume that, provided the air is sufficiently over-compressed, the compressed air used for operation of the breakers will always be free from water deposits.

By storing the major portion of the air at the over-compression level, overall space requirements are reduced. In the case of small installations where the reduced volume of air required can be economically accommodated within the operating air tank, the high pressure tank can be dispensed with: the cooled, over-compressed air in that case passing directly through the reducing valve into the operating air tank after it leaves the oil and water separator and check valve.

In the case of outdoor installations where the ambient temperature may vary widely and where the presence of moisture deposits is more likely to affect the satisfactory operation of the breakers, an activated alumina or other type of drier can be installed as an extra precaution.

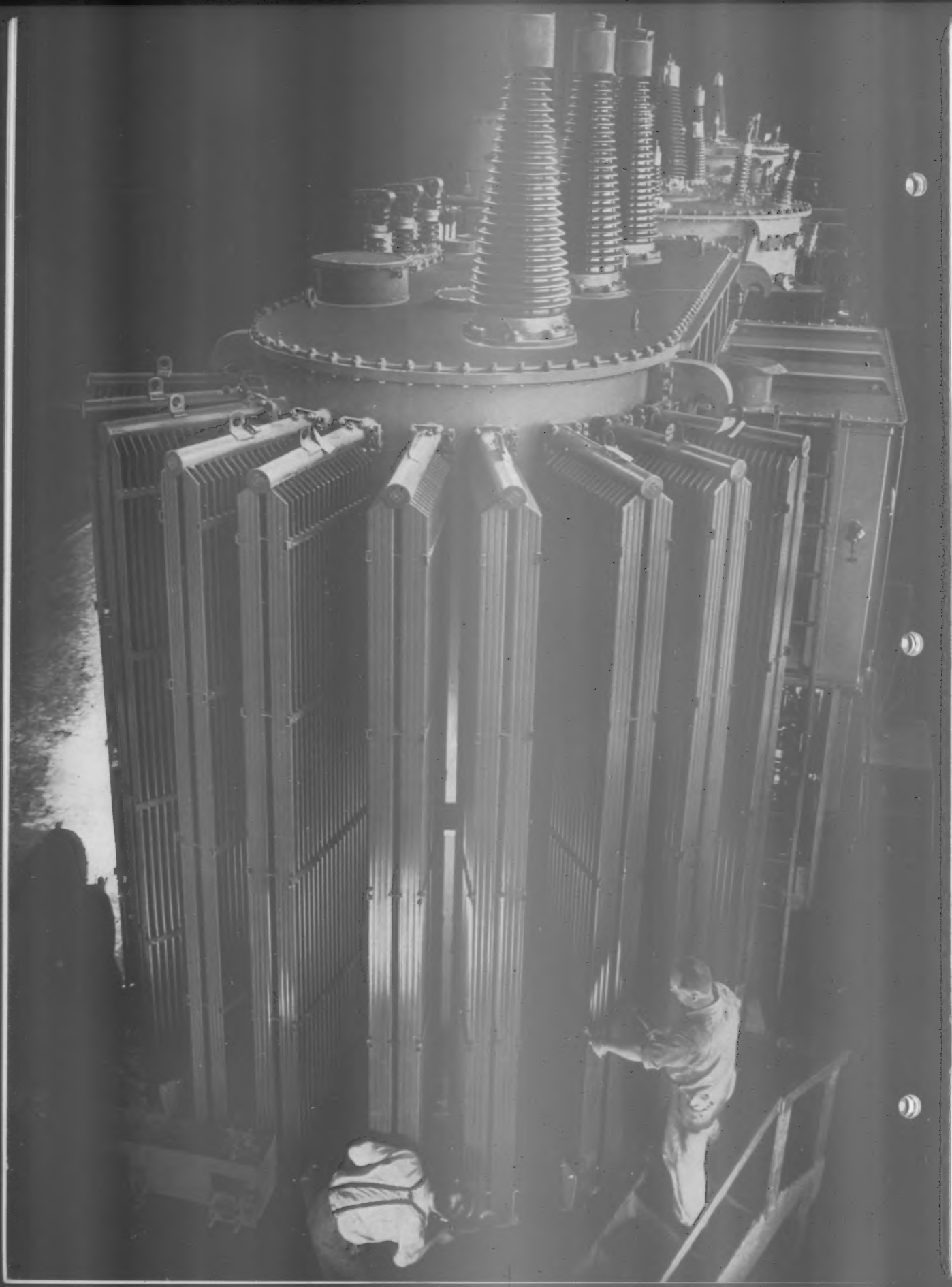
The reliability of the compressed air supply for both pneumatically operated oil circuit breakers and air blast circuit breakers can be increased by providing alternative supply circuits to the compressor motors, acting through automatic contactors arranged to throw over to an emergency supply when the normal supply fails.

Air storage and battery storage comparison

The air storage systems described above are the counterparts of the electrical storage battery with its charging equipment used with electrically-operated oil and air circuit breakers, and comparison between these two methods of storing operating energy is essential to a correct appraisal of the efficacy of compressed air as an operating means.

The storage battery has been in constant use for a great many years, and its characteristics are well known; but it is desirable to recapitulate here the various factors involved in its installation and maintenance because long usage tends to cause habitual discounting of factors which may have an important bearing on this comparison.

Batteries for operation of oil and air circuit breakers usually require 60 cells (125 volts d-c), while 120 cell, 250 volt batteries are used for some large outdoor installations. Such batteries occupy considerable space since, in order to obtain sufficient power for closing the breaker at the speed required to minimize burning during closing and at the same time to supply sufficient stored energy in the form of loaded springs for initial acceleration of the moving parts during opening, considerable ampere hour capacity is required in order to maintain adequate voltage at the solenoid. Because of the corrosive fumes given off by such batteries, it is usually considered advisable to install them in a separate room in order to minimize corrosion of metal parts, thereby necessitating a long run of duplicate, large cross-section, insulated connections to the breakers to prevent the volt-drop in the



connections, caused by the fairly heavy current flow, from reducing the voltage at the breaker operating solenoid terminals below permissible limits.

Such batteries are usually floated on a bus in parallel with a motor generator, and maintenance of the proper floating voltage at the battery terminals is a vital factor in battery life. Considerable attention must, therefore, be paid to maintenance of the necessary voltage. Nevertheless, hydrometer readings have to be taken at frequent intervals in order to determine the charge on individual cells since the internal resistance of the various cells may differ considerably. Cells of high internal resistance have then to be brought up to charge by overcharging the remainder of the battery, thereby enhancing the emission of corrosive gases. In addition, a supply of distilled water must be maintained and periodically added to individual cells.

The air storage system for the operation of pneumatically operated oil circuit breakers is integrally mounted with the breaker. Such a breaker requires no more space than an electrically-operated breaker of equivalent rating. Air storage systems for operation of air blast circuit breakers, however, are mounted separately from the breakers they are to operate and are usually assembled as a factory-built, self-contained unit in order to simplify installation. Practically the only connections required are the pipe connection between the operating air tank and the breaker air tanks, and the electrical connections to the compressor motors and their control devices.

Since an electrical supply is required for both the compressor motor of the air system and the motor driving the charging generator for the battery system, the question of electrical supplies can be left out of consideration in this comparison. The compressed air system, however, can be located in any convenient corner of a switchhouse near the breakers it is to operate; hence the pipe connections to the breakers do not have to be so long as the equivalent battery leads, nor do they have to be insulated.

Maintenance of the air system involves periodic emptying of water sumps and lubrication of compressors and motors. In addition, filters have to be replaced; and, where driers are used, the drying agent has to be periodically reactivated. It has been found, however, that the cost of maintenance for an air system is less than for an equivalent battery installation.

Two other factors have to be considered in this comparison. These are the current requirements of the solenoid control valves on the air blast breakers and the question of emergency station lighting. While the operation of air blast breakers is accomplished by means of compressed air, the entrance of the air into the breaker operating cylinders is initiated by electrical actuation of small solenoid valves, whose current requirements are very low compared to those of a conventional oil or air circuit breaker. A small amount of battery capacity must, therefore, be provided for this purpose.

In addition, the battery installation for operation of oil or air circuit breakers usually includes some capacity for operation of emergency station lighting, and this amount of battery capacity is still required in the case of air blast or pneumatically operated oil circuit breaker installations. The solenoid valve and emergency lighting current requirements can, of course, be taken care of by one battery; but, since the total requirements will be much lower than in the case of a battery which includes capacity for operation of oil or air circuit breakers, the voltage of the battery need not be as high, thereby reducing the number of battery cells. Such a battery would require much less space and could probably be safely mounted adjacent to the breakers, which would minimize the length and cross-section of the leads to the breakers. The reduction in battery voltage would be quite feasible in view of the fact that standardized lamps of adequate wattage are available for use at voltages as low as 32 volts.

Conclusion

That pneumatic operation of oil circuit breakers is economically feasible has been amply demonstrated, and the inherent characteristics of compressed air economically permits that processing of the air necessary for the satisfactory operation of air blast circuit breakers. The reliability of correctly processed compressed air as a means of storing energy for future use has been amply demonstrated by manifold applications, upon some of which depends the safety of many human lives. Compressed air systems for operation of circuit breakers can be economically installed and maintained, and their overall cost is less than that of the storage battery in general use today. When the higher interrupting efficiency obtainable by the use of compressed air for operation of circuit breakers and for circuit interruption is taken into consideration, it seems reasonable to predict that pneumatically operated oil and air blast circuit breakers will find a wider and wider acceptance in the future.

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AT LEFT: These giant power transformers, lined up on the erection floor ready to be tested, will bring power to vital industrial plants.

ENGINEERING FUNDAMENTALS

Hot spot temperature of transformers

● When a heat run is made on a transformer to determine the temperature rise, the standard practice is to measure the temperature of the hottest oil with a thermometer and to measure the electrical resistance of each winding between its terminals. By comparing this resistance with the resistance of the winding at a known temperature (cold resistance), the average temperature of the winding can be calculated from the equation

$$T_2 = \frac{R_2}{R_1}(234.5+T_1)-234.5$$

where R_1 is the resistance at temperature T_1, and R_2 is the resistance at temperature T_2. R_1 and R_2 are expressed in ohms; T_1 and T_2 in degrees C. The temperature T_2 so obtained is the average temperature of the winding; a portion of the copper will be hotter than this temperature, and a portion will be cooler.

Determining hottest temperature

Since the life of the transformer insulation depends, not on the average temperature, but on the hottest temperature, a method of determining the hottest temperature of the winding is highly desirable.

The most obvious method is to measure it directly with a thermocouple placed at the hottest spot, but this direct method cannot be generally applied for several reasons. It is difficult to determine the location of the hottest spot. It may be inaccessible; it may be impossible to reach it without destroying the insulation. The thermocouple as applied is likely to change the cooling conditions which normally exist, and often such thermocouples indicate the hot oil temperature instead of the copper temperature.

Because of such difficulties, the AIEE standards provide for an arbitrary correction of 10 C between average and hot spot copper temperature for oil-immersed, self-cooled transformers. According to this relation, the hot spot copper temperature at full load is equal to the average copper temperature at full load plus 10 C. This is the most satisfactory procedure which has been found to date.

Approximate method

An approximate method sometimes used is based on measurement of the temperature of the oil at the top and at the bottom of the transformer. The hot spot correction is taken as one-half the difference between these two temperatures. For most transformers, this method results in too large a correction so that, while it usually assures safe values, it is unduly pessimistic.

An examination of the oil circulation in a transformer will disclose the reason for this relationship.

If the oil circulation were of the simple type shown in Fig. 1, the temperature difference between the copper and its adjacent oil would be approximately the same at every point; and the oil temperature and the copper temperature would be represented by the two parallel straight lines of Fig. 2. From the geometry of the figure it is evident that the hot spot correction is equal to one-half the difference between the hot oil temperature and the cold oil temperature.

There is one other point which may be of interest in Fig. 2. It will be noted that the average copper temperature is less than the hot oil temperature. This paradox of the oil being hotter than the copper is startling until it is realized that the comparison is being made between the hottest oil and the average copper (not the hottest copper). This condition frequently exists on present-day transformers where the separation between the copper and oil lines of Fig. 2 is small because of the efficient cooling provided for the winding.

Actual conditions

The simple conditions shown in Figs. 1 and 2 do not apply very closely to actual transformers. Actual

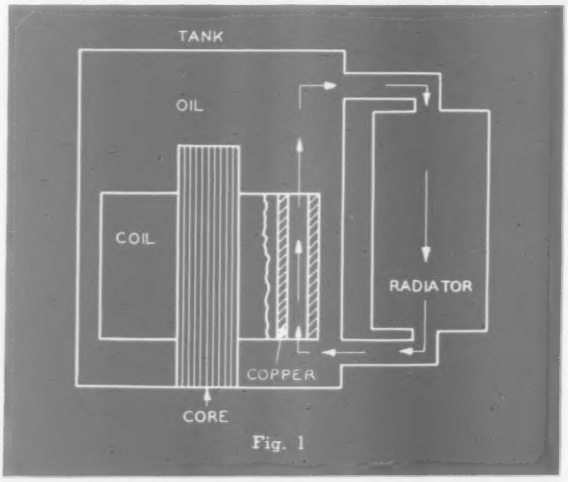


Fig. 1

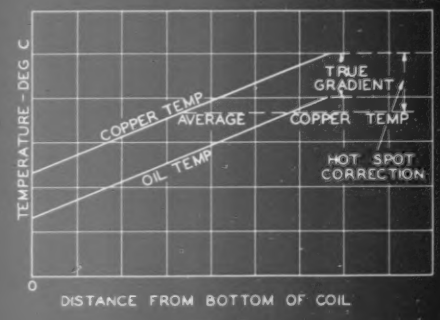


Fig. 2

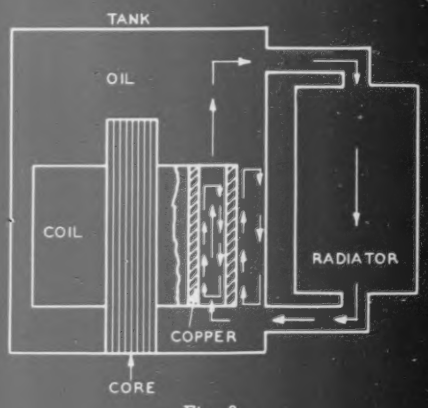


Fig. 3

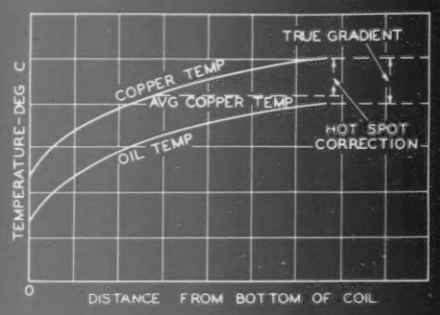


Fig. 4

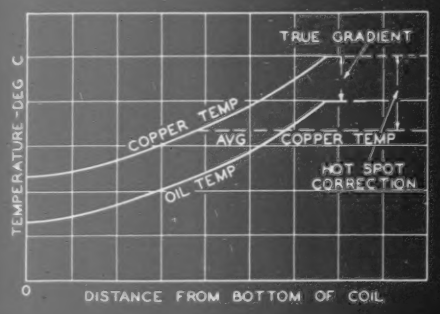


Fig. 5

transformers have extremely complex oil circulations, as indicated by Fig. 3. In addition to the main oil circulation as in Fig. 1, there are local oil currents circulating as shown in Fig. 3. The effect of these local currents is to cause the oil temperature curve to assume the shape shown in Fig. 4. It is obvious from the geometry of Fig. 4 that the hot spot correction is not equal to one-half the temperature difference between the hot and cold oil but is equal to something less than this value.

It is possible to have oil and copper temperature curves as in Fig. 5, in which the hot spot correction is greater than one-half the difference between the hot and cold oil temperatures. However, this condition would be unusual. Experimental tests, in which the oil temperatures in the ducts were measured, indicate that the relations of Fig. 4 are the most common for modern transformers. Because of these complex relations and the difficulty of direct measurement, no precision method of obtaining hot spot temperature suitable for general use is available; and the best practice for present-day transformers is the use of the standard AIEE hot spot correction of 10 C.

The difference in temperature between the hottest copper and the adjacent hottest oil is the temperature difference between copper and oil which is of interest in heating problems. This difference is sometimes called the "true gradient" of the transformer. It is possible to measure or calculate the temperature of the hottest oil with satisfactory accuracy. The hottest copper will be adjacent to the hottest oil so that, if the true gradient for any load is added to the hottest oil for that load, the hot spot copper temperature is obtained. For most transformers, the true gradient for loads lasting an hour or longer will vary with the copper loss according to the relation

$$G_2 = G_1 \left(\frac{W_2}{W_1}\right)^K$$

where G_1 is the true gradient with copper loss W_1
G_2 is the true gradient with copper loss W_2

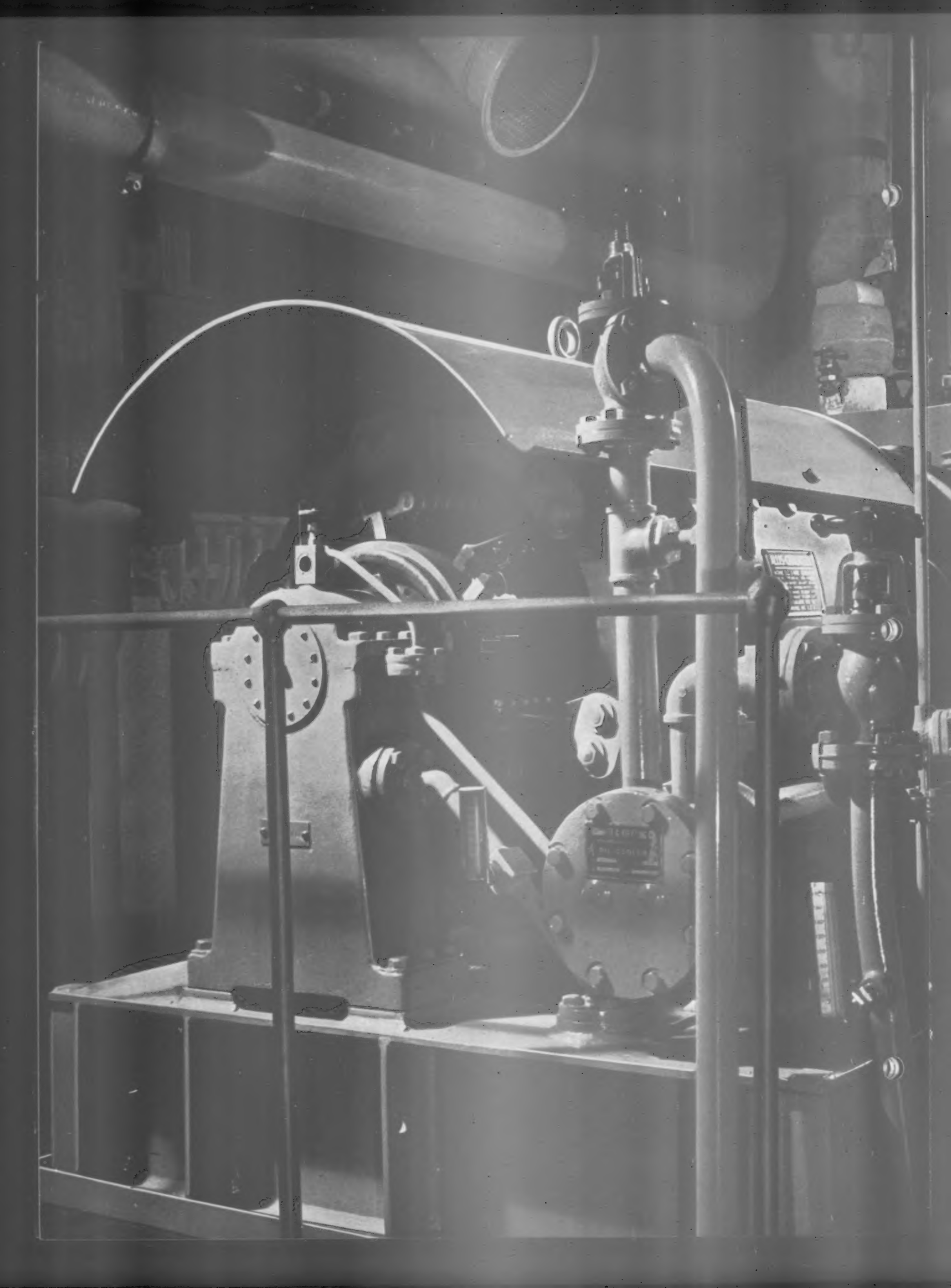
and K is a constant with a value between 0.8 and 1.0 for modern power transformers.

If the change in resistance of the copper over the temperature range considered is negligible, this reduces to $G_2 = G_1 \left(\frac{L_2}{L_1}\right)^{K_1}$

where G_1 is the true gradient with percent load L_1
G_2 is the true gradient with percent load L_2

and K has a value between 1.6 and 2.0 for modern power transformers. The hot spot temperature for any load is equal to the hot oil temperature plus the true gradient for that load.

ON FOLLOWING PAGES: As necessary as fighting ships during wartime are the cargo vessels that bring supplies to our Army, Navy, and allies. Here are two 250 kw auxiliary turbo-generator sets aboard a recently launched C1-A ship.



DYNAMOS

INVENTIONS "ON SALE"

Invented articles may be sold before filing application for patent without detracting from resulting United States patent rights. When is an article "on sale," and how long may it be on sale before filing an application for a patent covering it?

D. Journeaux

PATENT ATTORNEY • ALLIS-CHALMERS MANUFACTURING COMPANY

● In spite of the intimate dependence of our daily life on innumerable inventions, the monetary value of new inventions is usually quite unpredictable and is often, therefore, a matter of opinion. In this connection it is sometimes implied that inventors, as a class, are inclined to place an excessive value on their inventions. This is quite likely to be true of an inventor whose invention is outside of the field of his trade or profession and who therefore may lack the right yardstick for measuring its value. On the other hand, a manufacturer owning an invention, whether made by himself or assigned to him by someone else, may be expected to look at it with a more critical eye. To him the value of an invention resides very often in its chances of immediate commercial success, and money spent on a commercially untried invention may be an unwise investment, particularly for a man with limited capital.

Patent protection must be sought promptly

This may explain why manufacturers have often put valuable inventions on the market without taking the obvious step of first patenting them. If an invention is a commercial failure, money spent to patent it may be wasted. If it sells well, however, it is eventually seized by competitors, and then its originator may realize that the few hundred dollars that a patent would cost might be well spent. Often the question was raised, alas, too late, for the patent statutes require inventors to seek patent protection promptly. The latest that a patent application may now be filed is one year after the invention has been in public use or on sale in this country for the first time, but a delay of two years was permitted up to a little over a year ago. Failure to comply with this requirement renders the resulting patent invalid. To avoid any confusion, it may be stated that the public use or sale refers to an embodiment of the invention; the statute makes no reference to sales of rights to an invention.

A requirement of this nature, far from being an imposition, is really a concession to inventors. Any delay in applying for a patent defers the time at which the inventor will have to relinquish the invention to the public. Under most circumstances, the allowed time cannot be extended; and, as with other laws, ignorance of patent laws is no excuse. If an inventor, after his invention has been on the market for one year with or without his consent, has not applied for a patent, it will be presumed that he does not desire it. His failure to apply for a patent is taken as evidence of his intent to abandon his invention to the public.

In recent years it has been rather infrequent for patentees to see their patents invalidated by premature sales of their inventions. Apparently prospective patentees nowadays are well coached by their counsel as to the legal requirements. These requirements, of which the full import could only be guessed toward the end of the last century, have now been clarified by numerous court decisions. The efforts of tardy patentees to prove that their inventions were not on sale outside of the permissible period have caused the courts to look into a sufficient variety of circumstances of sales to satisfy even the most fastidious inquirer.

Inventions on sale

One of the earliest principles established by the courts in this connection is that an invention is to be considered "on sale" not only when it is sold but even when it is merely offered for sale. But an invention cannot be considered offered for sale until it has been completed by being at least tried out with all its elements or, in the language of the courts, "reduced to practice."

It is reasonable enough to disregard offers to sell an invention before it has been fully tested and found satisfactory. The language of the statute seems to indicate that the sales it refers to are only those that may lead to immediate use of the invention by the public. But even a very simple invention is apt to have fatal defects or disadvantages which may not be obvious upon casual inspection. A final test of the invention may show the need of considerable modification, in which case any "sale" made before test is

reduced to a mere prophecy. Any "sale" of an untried invention is therefore questionable.

Invention exposed for sale

To establish that an invention was on sale, it is not necessary to prove any offer to sell to any particular person. One sample of the wagon jack, shown in Fig. 1, was exposed for sale in a hardware store in 1888, more than two years before its inventor applied for a patent in 1890. The jack may or may not have been offered to any customer in 1888, and in fact it was sold only in 1899. But its mere display was sufficient to cause the patent to be invalidated in a suit terminated in 1901. The patentee's contention in the suit was that the jack had not yet been made at the time it was supposed to be on sale. This defense was original and would possibly have been successful but for the fact that it was disproved by the testimony of credible witnesses.

Invention on price list

Although an article can be "on sale" only after at least one sample of it has been made, it is not necessary that the object itself be shown to prospective buyers.

This became apparent as early as 1883 from litigation involving the roller skate shown in Fig. 3. Its inventor, the pioneer in the invention of "parlor skates" as they were then called, had already made skates having their wheel bearings mounted on brackets through inclined pivots so that the wheels would cock in response to shifting of the weight of the skater to take curves. The skate in suit was an improvement of this earlier skate, differing from it in details. The inventor included it in a price list which he distributed early in 1863, more than two years before he applied for a patent covering its improved construction. This was one of the reasons for which his patent was ultimately held invalid.

Design exhibited for sale

In many respects the patent laws make no distinctions between the so-called mechanical patents, which are the only patents known to most people, and the less familiar design patents, such as those illustrated in Figs. 2 and 5, which are used to protect ornamental designs. The restriction of sales before patent application applies equally to both kinds of patents and was fatal to the design patent covering the lamp post shown in Fig. 2. The patentee applied for his patent in 1878, but unfortunately it was proved in a suit decided in 1880 that another manufacturer had submitted the same design to a township in 1875. Only a drawing was exhibited with an offer to sell the lamp posts, but lamp posts differing from that offered to the township only in an immaterial detail had already been made. The design was therefore on sale, and the patent was properly held invalid for that reason and because of public use of the design.

Invention sold when accepted

Since an invention is not on sale until it has been put in tangible form, it may be asked at what time an

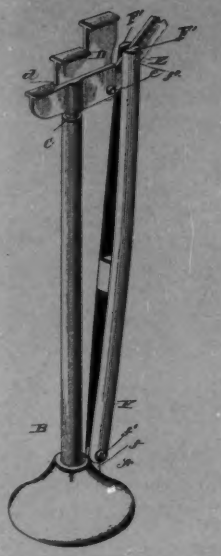


Fig. 1 — C. Emons' wagon jack, displayed for sale in 1888, invalidating patent applied for in 1890.

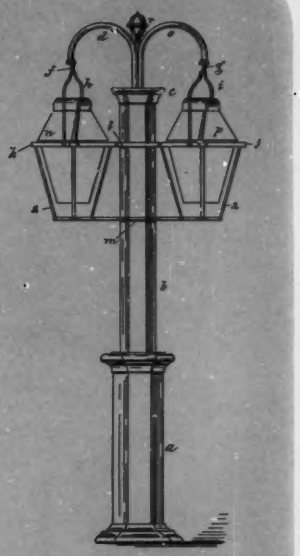


Fig. 2 — G. D. Burton's lamp post, offered for sale in 1875. Design patent, applied for in 1878, rendered invalid.

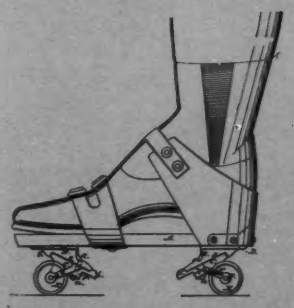


Fig. 3 — J. L. Plimpton's parlor skate, included in a price list in 1863, rendered void the patent applied for in 1865.

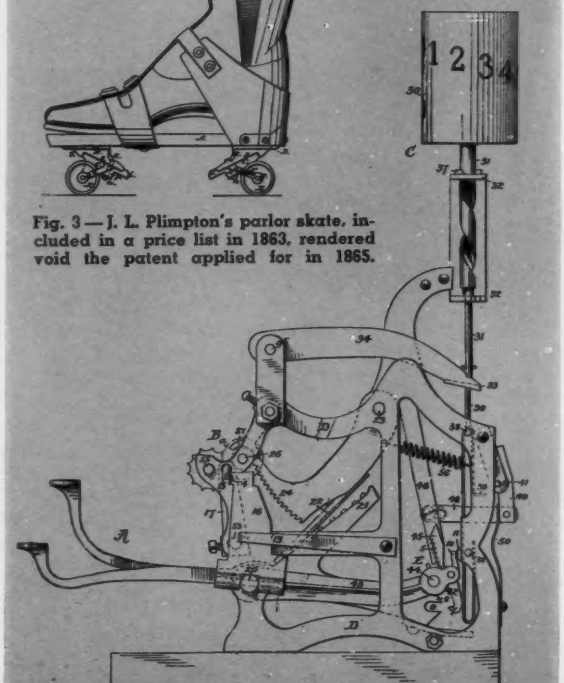


Fig. 4 — C. A. Juengst's cash register, invented to order and sold in 1886, nullifying the patent applied for in 1890.

invention becomes "on sale" when an embodiment of it is made only after receipt of a purchase order. The question was answered in several court decisions, one of which involved the adding cash register shown in Fig. 4. This machine contained an interlock or coupler between the keys to insure that all keys depressed simultaneously would register even if some were released before completing their stroke.

In this case the order for the machine was placed with the manufacturer before he made the invention in question, neither the seller nor the buyer then knowing how the machine was going to be arranged. It was only in the course of the manufacture of the machine and after evolving an unsuccessful design that the manufacturer invented the coupler. The machine containing the coupler was delivered to the buyer in 1886. It was held in a suit decided in 1910 that the sale was completed by the delivery and acceptance of the machine, the title to which only then passed from the seller to the buyer. Taking place more than two years before the patent was applied for in 1890, the completion of the sale rendered the patent void. The court also found good reason to declare that the patenting of the machine was just an afterthought.

The fact that the machine was manufactured and delivered upon an advance order rather than manufactured before an order was obtained did not alter the effect of the sale. But, if the invention had been made by the buyer instead of by the seller, the sale of the machine would not have been a sale of the invention. The buyer would then have been paying for having his invention embodied in a machine, but he would not have paid for his own invention. A sale of the invention can only be made to a member of the public: in other words, to anybody except the inventor himself.

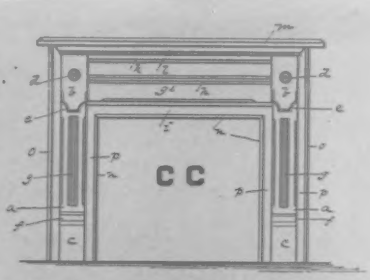


Fig. 5 — W. Anderson's mantel design, shipped and billed in 1888, rendering invalid the design patent applied for more than two years later.

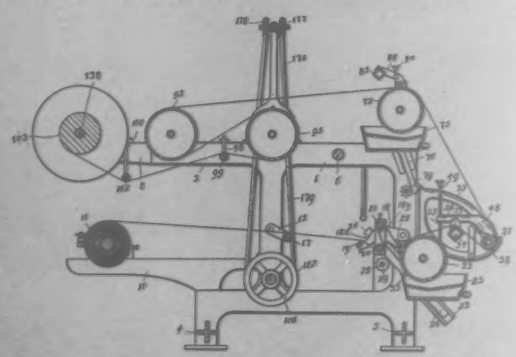


Fig. 6 — C. W. Mayer's paper coating machine, for which bill of sale in 1908 invalidated patent applied for in 1911.

Sale completed by implied acceptance

A sale of an article embodying an invention may be completed even if the acceptance of the article is not expressed but merely implied. In the case of the fireplace mantel shown in Fig. 5, one mantel was shipped to a purchaser in 1888 and shortly thereafter was billed to him. The bill was rendered two years and two days before the manufacturer applied for a design patent covering the mantel. There was no formal acceptance of the mantel, but the fact that the invoice had not been protested was apparently sufficient evidence of the goods' being accepted. The patent was held invalid in 1893 although the mantel was paid for less than two years before the patent was applied for.

Sale with delayed delivery

Sometimes a sale may even be completed before actual delivery of the article sold. Such a sale was fatal to the patent on the coating machine shown in Fig. 6. The patented structure comprises a heated coating roller closely adjacent to a heated equalizing scraper and a cooled smoothing roller and is an improvement over a machine previously built by the inventor in 1908 on borrowed money. The latter machine was used by the inventor to make carbon paper for his financial backer. Instead of repaying the loan, the inventor gave his backer a bill of sale of the machine, and soon thereafter the buyer leased the machine back to the inventor's wife.

In a suit decided in 1918, the inventor contended that this queer sequence of transactions did not constitute a sale and that the machine was simply security for a mortgage. The court, however, held the sale completed by the transmission of the bill of sale, more than two years before the patent was applied for in 1911. In fact, the machine was actually delivered to the buyer in 1910. Even though the machine sold was perhaps imperfect and the structure shown in the patent greatly improved, the sale invalidated the patent because the machine sold was within the scope of the patent claims.

Conditional sales

The completion of a sale by acceptance of the article sold is not affected by any money-back guarantee or other guarantee of satisfactory operation, as long as it is not agreed between the seller and the buyer that the article sold is purely or at least principally experimental and that the sale is made for the purpose of testing the invention.

Conditional sales were sufficient to invalidate the patent on the stove shown in Fig. 7. The stove consisted of a cast iron frame supporting a double wall

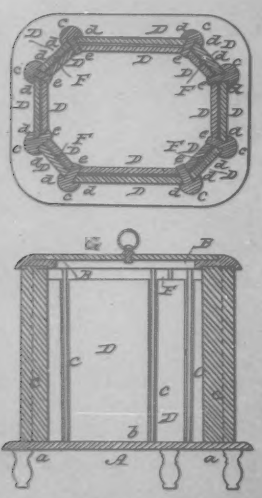


Fig. 7 — P. Dodge's soapstone stove, of which sales on trial in 1854 voided the patent applied for in 1857.

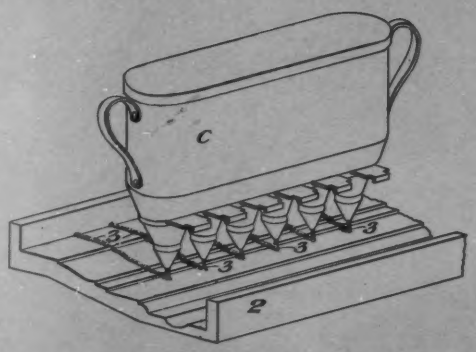


Fig. 8 — P. E. Denivelle's process of making stone, held "sold" in 1910, thereby invalidating the patent applied for in 1915.

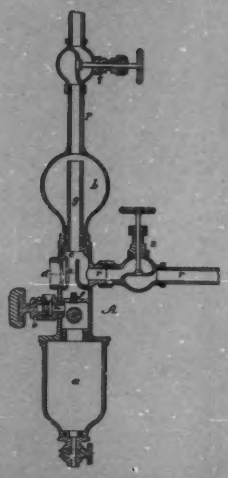


Fig. 9 — W. H. Craig's engine lubricator, sold after modification in early 1883, invalidating the patent applied for in late 1885 for the unmodified form.

of soapstone slabs. The drawing looks a trifle incomplete, but the patent helpfully states that the stove may be provided with a door and with stove pipe. A few stoves were sold on trial in 1854, to be returned if they were not satisfactory to the buyers. Taking place over two years before the inventor applied for a patent in 1857, they rendered the patent invalid. The patentee's contention that the stoves were experimental was unavailing in a suit decided in 1880 since their conditional sale was not a proof that the inventor had any doubts as to their operation and intended to use his customers as guinea pigs. He had all the facilities needed for testing the stoves himself and did not need to sell them to find out their defects.

Sale of process

Although the word "sale" brings to mind a transaction involving a tangible object, the principles governing the effects of sales of patented inventions have been extended to processes. The process of making artificial stone shown in Fig. 8 was so involved. This figure shows a mold into which are poured a series of veins of dense cement, the veins afterwards to be backed by a layer of porous cement showing between the veins to imitate rock comprising alternate dense and porous layers.

This process was used by the inventor in 1910 for making the strikingly attractive facings of the Pennsylvania Station in New York. The job was completed and accepted more than two years before a patent claiming both the process and the product was applied for in 1915. Although the sale of the stone was subject to replacement of material showing defects within one year, it had the same effect as an unconditional sale. It was held in 1925 that both the process and the product of the invention had been placed on sale and sold for a profit outside of the permissible period and that the patent therefore was invalid.

Ineffective invention sold

When a sale of a novel article is made, the buyer is not always aware of the nature of the invention embodied in the article he is buying or even that it contains any invention. The effect of the sale on a subsequently procured patent remains, nevertheless, the same even if the invention has been rendered ineffective in the article sold. This actually happened with respect to the sight feed lubricator for steam engines shown in Fig. 9. This lubricator comprises a pipe for connecting the condenser to the boiler and a short inner pipe for conducting live steam from the condenser to the oil discharge pipe.

In a suit decided in 1896, the inventor testified that one such lubricator was tested on a prospective buyer's engine in 1883, but that the inner pipe was plugged up before the lubricator was finally sold. This took place more than two years before he applied for a patent for the lubricator as originally made, including the inner pipe. It was held that the invention had been sold because it was embodied in the lubricator, so that the buyer could avail himself of it simply by removing the plug.

Sale to test market

One of the oldest excuses used to explain sales of an invention before patenting is that the sales were made to test the salability of the invention on the market. Even if it is true, such reason does not avoid the effect of a sale on a patent applied for more than two years later. In a celebrated decision, the Supreme Court in 1877 held invalid the patent on the fruit jar shown in Fig 10 because of sales of this character.

The jar was intended to be an improvement of another jar of the same inventor, still popularly known as a Mason jar. The inventor had a few samples of the modified jar made in 1859. Some of these were sold at that time for three or four dollars a dozen for the purpose of testing their popularity with the public and also to make a little easy money. This was sufficient to invalidate the patent, which was applied for only in 1868, when the inventor was stimulated into activity by seeing jars similar to his being sold on the market.

Sale of new article not experimental

The test of the market being an insufficient excuse, some other had to be found by the inventor of the bed spring shown in Fig. 11. This spring had the banks of coils tied top and bottom by tie rods and hooks, a feature which was apparently novel when the spring began to be sold in the normal course of business early in 1880. Naturally, at first the putting of the spring on sale was something of a gamble, but the same can be said of almost any article of commerce.

The spring, however, sold well; and, evidently as an afterthought, the inventor made his patent application late in 1882. This was too late, even though the patentee obtained his patent in less than ten

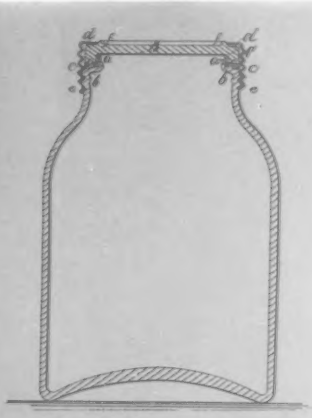


Fig. 10—J. L. Mason's modified fruit jar, of which samples sold in 1859 invalidated the patent applied for in 1868.

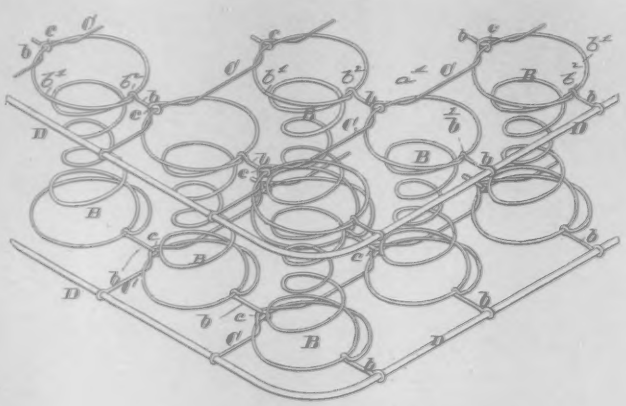


Fig. 11—J. G. Smith's bed spring, sold in quantities in 1880, invalidating the patent applied for over two years later.

Fig. 12—A. M. Swain's hydraulic turbine, sold without experimentation in 1879, rendering void the patent applied for over two years later.

weeks, a feat seldom equaled today. In a suit the inventor tried to save his patent by passing off the early sales of springs as an experiment. It was evident, however, that those sales were not made primarily for the purpose of discovering the defects of the invention and for enabling the inventor to remedy them. The decision of the court, handed down in 1893, therefore held the patent invalid.

Experimental sale must be coupled with tests

Experiment was also the excuse for the untimely sale of the hydraulic turbine shown in Fig. 12. This turbine is of the double runner type discharging into a single draft tube. The inventor placed a partition in the draft tube for minimizing eddies resulting from the meeting of the two water streams. One turbine, sold and installed in 1879, was complete and fully developed; but it could not operate at its full efficiency because it had been connected to existing undersize water pipes.

Although the turbine had been untried before that time, this first sale was not experimental because it was not conducted as an experiment. The sale of the machine was the inventor's first opportunity to test it, but he did nothing to determine the efficiency and to find out what improvements might be necessary. In fact, the machine was so installed that tests made on it would have been meaningless. For this reason, the claims of a patent applied for more than two years later in 1881, directed to the partition within the draft tube, were held invalid in 1901.

Experimental sale seldom proven

In several of the instances above considered, as well as in other litigations, the improvident patentee had no other recourse than to try and present a premature sale of his invention as having been for experimental purposes in order to save his patent. Occasionally this argument has been successful, and a single sale of an invention by the inventor has been held permissible where the inventor was unable otherwise to test his invention properly. For example, the inventor may be impecunious and unable to secure the capital required for building his device otherwise than by a sale, and he may not have the facilities for testing his invention under the conditions of its intended operation.

The proof of the inventor's intention of using the device sold for his experiments should be clear. He should retain control over his invention with the right to alter it as he sees fit to overcome the defects. Even so, the inventor runs the chance that some unthought-of circumstance will tend to disprove that the sale was for experimental purposes. It is certainly safer to consider any sale of a new invention to be a regular sale and to follow it with the filing of a patent application within the one year period now set by the statute.

New Motor with All-Around Protection

One of the most important motor improvements in years is the "Safety-Circle" protection of the new line of Lo-Maintenance Motors. Specially developed to give the motor complete all-around protection, the "Safety-Circle" is a wide, solid rib — integrally cast as part of the frame—which forms an unbroken circle of protection around the stator.

One-piece cast frame and cast end-shields guard the motor from exterior knocks and abuse. A more liberal use of electrical materials makes this motor internally and electrically stronger because current and magnetic densities are less extreme. Improved bearing design delivers smoother performance with full-flow lubrication and easier maintenance.

Additional cross strength is built into the distortionless stator for maximum power efficiency. Rotor is keyed to shaft for strength, and its outer surface is turned for smoothness and an accurate air-gap.

New Standard Dimension Current Transformers

Following adoption of standard primary ratings for current transformers by EEI and NEMA, there have been developed three new types of current transformers, on which distribution began early this year.

Conforming to the standard major dimensions in the three ratings—5 kv, 8.7 kv, 15 kv—the new transformers have standard base dimensions and primary bar heights and dimensions, making possible free interchange of this equipment on all metering installations. The units are designated Type MKE (5 kv), K2E (8.7 kv) and K3E (15 kv).

The new types are built for high accuracy, high impulse strength, and have uniform slotted terminals to take a wide range of connectors on the primary bars. They are designed for heavy-burden accurate metering, relay and control applications. An extra-cycle impregnation process seals the entire unit against damage due to moisture or industrial gases.

It is expected that the new standardized line will make specifying and buying easier, facilitate installation, and simplify stock problems.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.

THE GAS TURBINE
III. THERMAL EFFICIENCY AND APPLICATIONS*

Efficiency is demanded of every prime mover. This critical characteristic of the gas turbine is herein carefully considered, as are present and future fields of application for this interesting product of modern metallurgy and aerodynamic research.

Dr. J. T. Rettaliata

STEAM TURBINE DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● The thermal efficiency, that is, the ratio of the heat equivalents of the useful output and fuel supplied in a given time, of a gas turbine as affected by turbine inlet temperature and pressure ratio is shown in Fig. 25. The solid lines represent actual cycles in which losses have been incorporated, such as cycle AB′C′D″ in Fig. 21 (Part II), and the broken line indicates a theoretical cycle without losses, such as ABCD. The thermal efficiencies given by the curves are based on the lower heating value of the fuel.

Reference to Fig. 25 will show that operation on a non-regenerative cycle at 1000 F will produce a thermal efficiency at the coupling of about 16 percent with a pressure ratio between four and five. Tests conducted by Dr. Stodola[12] on a 4000 kw gas turbine power unit, operating at 1000 F on a non-regenerative cycle, indicate that coupling thermal efficiencies of 18.04 percent were obtained.

Dictated by permissible operating temperatures, the present gas turbine units have been designed with a pressure ratio of about four in order to achieve maximum thermal efficiency.

It can be seen from Fig. 25 that operation at temperatures much below 1000 F is not conducive to the attainment of desirable thermal efficiencies. When it is considered that the early experimenters were compelled, because of inferior materials, to restrict their endeavors to the region shown by the lower temperature curves, it is not surprising that only mediocre success was achieved. Furthermore, when the less favorable efficiencies of the earlier turbines and compressors are taken into account, the poor thermal efficiencies indicated by these lower curves must be depreciated still more.

Regeneration—theoretical cycle

The thermal efficiency of a cycle may be readily improved by the introduction of a heat exchanger wherein, prior to its entry into the combustion chamber, the air discharged from the compressor is preheated by the turbine exhaust gas. Such an arrangement affords a simple and effective means of accomplishing more economical operation by employing stationary equipment requiring comparatively negligible maintenance.

That there exists an excellent opportunity to improve performance by the use of heat recovery apparatus is apparent upon referring to Fig. 21. The temperatures of the turbine exhaust gases are 605 F and 977 F for the 1000 F and 1500 F cycles, respectively. If, instead of discharging these relatively high temperature gases to the atmosphere and thereby receiving no benefit from the thermal energy which they contain, they are used to raise the temperature of the 356 F air leaving the compressor, then less fuel will be needed per pound of air to produce the required turbine inlet temperature.

Incorporation of a heat exchanger into a cycle must be undertaken with caution, however, since an excessive pressure loss through it may easily nullify any increase in efficiency that could otherwise be realized. Nevertheless, when properly designed, improved performance is readily attainable.

Figure 26 shows on the temperature-entropy, enthalpy-entropy plane a theoretical cycle with associated areas representing quantities of heat transferred from the exhaust gas to the air discharged from the compressor. The cycle, working between the pressure limits of P_1 and P_2, is designated by ABCD.

* This is the third of three definitive articles by Dr. Rettaliata on the history and modern status of the combustion gas turbine. Parts I and II appeared in the Sept., 1941, and Dec., 1941, issues, respectively, of Allis-Chalmers ELECTRICAL REVIEW. The author recently received the 1941 Junior Award of the American Society of Mechanical Engineers for his paper, "The Combustion Gas Turbine," ASME Trans., Feb., 1941.

(12) A. Stodola, "Load Tests of a Combustion Turbine," Power, Feb., 1940.

Assuming a counter-flow heat exchanger of infinite surface, the turbine exhaust gas at temperature T_D will be theoretically cooled along the constant pressure line P_2 until it reaches a temperature T_Y. At the same time the air discharged from the compressor will be heated at constant pressure P_1 by the gas so that its temperature will be increased from T_B, its value after isentropic compression, to a value T_Q equal to T_D, the temperature of the exhaust gas leaving the turbine.

If the specific heats and quantities of the air and gas were identical, then the temperature of the gas leaving the heat exchanger would be the same as that of the air entering, namely, T_B. Due to the slightly increased gas weight resulting from the addition of fuel, the exhaust gas will not be cooled to a temperature as low as T_B but instead will have a temperature T_Y which may be obtained from the relation

$$\int_{T_B}^{T_Q}(a+bT+cT^2)\,dT=(1+x)\int_{T_Y}^{T_D}(a'+b'T+c'T^2)dT, \quad (16)$$

where: T_D=temperature of gas entering heat exchanger, deg F abs

T_Y=temperature of gas leaving heat exchanger, deg F abs

T_B=temperature of air entering heat exchanger, deg F abs

T_Q=temperature of air leaving heat exchanger, deg F abs

a, b, c, x=quantities previously defined

a′, b′, c′=coefficients in variable specific heat equation for turbine exhaust gas.

Upon integration and substitution of limits equation (16) becomes

$$a(T_Q-T_B)+\frac{b}{2}(T_Q^2-T_B^2)+\frac{c}{3}(T_Q^3-T_B^3)$$
$$=(1+x)\left[a'(T_D-T_Y)+\frac{b'}{2}(T_D^2-T_Y^2)+\frac{c'}{3}(T_D^3-T_Y^3)\right] \quad \ldots\ldots(17)$$

which may be solved for T_Y.

Since the air and gas in the heat exchanger experience practically the same temperature range and are of essentially the same composition, the specific heats may be assumed to have the same average value, thus enabling T_Y to be determined from the simplified relation

$$T_Y=\frac{x\,T_D+T_B}{(1+x)} \quad \ldots\ldots(18)$$

The heat released per pound of gas in the heat exchanger is equivalent to the sectioned area

$$KYDN=h_D-h_Y,$$

and the heat absorbed per pound of air is represented by the sectioned area

$$EBQG=h_Q-h_B.$$

The heat to be added by the fuel per pound of air is, therefore, equivalent to area

$$GQCN=h_C-h_Q$$

and is less than area

$$EBCN=h_C-h_B$$

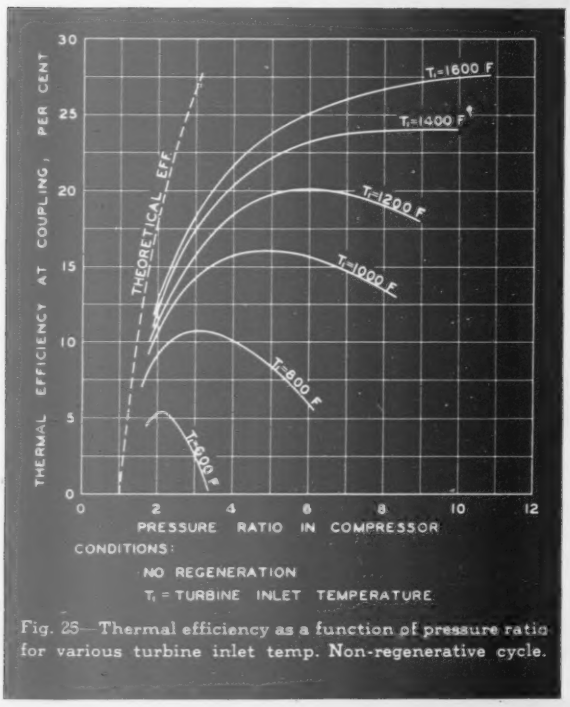


Fig. 25—Thermal efficiency as a function of pressure ratio for various turbine inlet temp. Non-regenerative cycle.

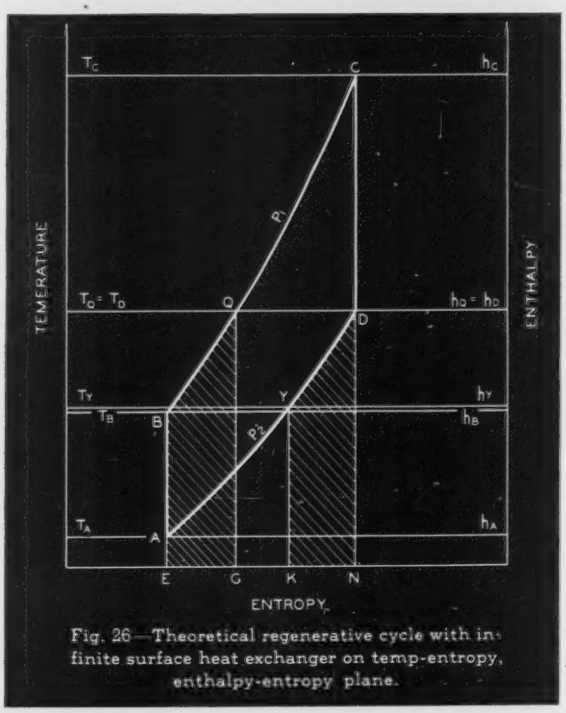


Fig. 26—Theoretical regenerative cycle with infinite surface heat exchanger on temp-entropy, enthalpy-entropy plane.

which represents the heat furnished by the fuel in a non-regenerative cycle.

Consequently, the regenerative cycle produces a thermal efficiency

$$\left[\frac{h_C-h_B+y'}{h_C-h_Q+y}-1\right]\times 100 \quad \ldots\ldots\ldots (19)$$

percent greater than that obtainable without heat recovery apparatus; where y and y′ are the amounts of heat added to the fuel itself per pound of air for the regenerative and non-regenerative cycles, respectively.

Regeneration—actual cycle with infinite surface heat exchanger

An actual cycle operating between the pressure limits of P_1 and P_2 in the compressor and P'_1 and P'_2 in the turbine is depicted by AB′C′D′ in Fig. 27. In comparison with the theoretical cycle, passage of the air through the heat exchanger and combustion chamber has entailed a pressure loss of $P_1-P'_1$, and discharge of the exhaust gas into the heat exchanger has resulted in an increase in turbine exhaust pressure of P'_2-P_2. In the interest of obtaining optimum performance such pressure drops should be kept at a minimum.

Even though of abstract significance when associated with an actual cycle, a heat exchanger having infinite surface is assumed for purposes of discussion. The heat available for preheating will depend upon the difference in actual temperatures, $T_{D'}-T_{B'}$, of the gas and air after polytropic expansion and compression, respectively.

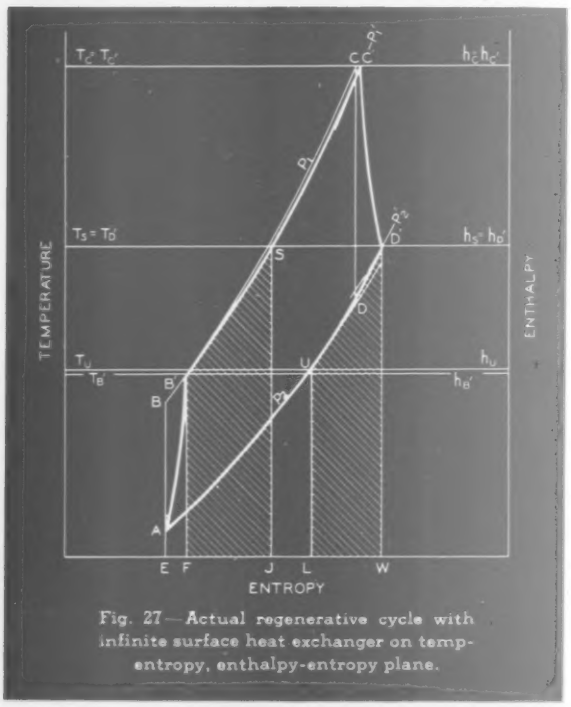


Fig. 27—Actual regenerative cycle with infinite surface heat exchanger on temp-entropy, enthalpy-entropy plane.

Thus, the heat given up per pound of exhaust gas is represented by the sectioned area LUD′W which is not equivalent to the difference in enthalpies at the extremities of the state change path, as was the case for the theoretical cycle, because the existence of a pressure drop in the heat exchanger means that the path D′U is not executed at constant pressure but instead at progressively decreasing pressures between P'_2 and P_2.

The actual heat equivalent of area LUD′W is equal to the product of the average specific heat existing for the actual path traversed and the change in temperature along the path. This specific heat may be obtained from the expression

$$c_n=c_v\,\frac{k-n}{1-n} \quad \ldots\ldots\ldots (20)$$

where: c_n=average specific heat for path between temperature limits of path, Btu per deg F per lb

c_v=average specific heat at constant volume between temperature limits of path, Btu per deg F per lb

k=average isentropic exponent between temperature limits of path

n=average actual polytropic exponent between temperature limits of path.

In equation (20) the actual polytropic exponent n for the path D′U may be obtained from the expression

$$n=\frac{\log P'_2-\log P_2}{\log V_U-\log V_{D'}} \quad \ldots\ldots\ldots (21)$$

where: P'_2=pressure of gas entering heat exchanger, psi, abs

P_2=pressure of gas leaving heat exchanger, psi, abs

V'_D=specific volume of gas entering heat exchanger, cu ft per lb

V_U=specific volume of gas leaving heat exchanger, cu ft per lb.

Therefore, the heat released by the exhaust gas in the heat exchanger may be expressed, in Btu per pound of gas, as

$$\Delta h_{D'U}=c_n\,(T_{D'}-T_U).$$

In a similar manner the heat equivalent of area FB′SJ, representing the heat absorbed by the air in the heat exchanger, may be obtained as well as the heat supplied by the fuel.

As will be noted from Fig. 27, the assumption of a heat exchanger having infinite surface entails heating of the air to a temperature T_S, the same as that of the gas at the turbine exhaust. For reasons previously given in the case of the theoretical cycle of Fig. 26, the temperature T_U, to which the exhaust gas is cooled, is higher than the temperature of the air after polytropic compression. However, due to the pressure losses in cycle AB′C′D′, the difference between temperatures T_U and $T_{B'}$ will be less than that between temperature T_Y and T_B for the theoretical cycle ABCD of Fig. 26. With excessive pressure drops the air will

be unable to attain a temperature equal to $T_{D'}$ even with the assumed infinite surface of the heat exchanger.

Regeneration—actual cycle with finite surface heat exchanger

An actual cycle embodying a heat exchanger of finite surface is shown on the temperature-entropy, enthalpy-entropy plane in Fig. 28 by AB′C′D′. As before, the compressor is assumed to operate between the pressure limits of P_1 and P_2 and the turbine between P'_1 and P'_2.

Restricting the surface of the heat exchanger to a finite value results in terminal differences of ΔT_1 and ΔT_2 between the air and gas temperatures at the higher and lower temperature ends of the heat exchanger, respectively. Obviously the greater the surface the less will be the terminal difference.

The heat abstracted from each pound of turbine exhaust gas is represented by sectioned area MVD′W, and the heat absorbed per pound of air is depicted by sectioned area FB′RH. The magnitudes of the thermal equivalents of these areas may be determined by the procedure previously outlined.

The foregoing discussion has involved theoretical and actual cycles comprising heat recovery apparatus of both finite and infinite surfaces. Fig. 29 shows, as a function of pressure ratio, the thermal efficiencies likely of attainment with the various cycles considered. In addition, curves B, F, and G are included for comparison purposes.

All of the curves in Fig. 29 are based on the lower heating value of the fuel and are corrected for the fuel consumed, except curve B, representing a theoretical non-regenerative cycle, which is independent of temperature, as will be shown later. All curves depicting thermal efficiencies of actual cycles are based on internal turbine and compressor efficiencies of 86 and 84 percent, respectively, and a loss of one one-half of one percent has been assumed for bearings, glands, and radiation.

Between the compressor discharge and turbine inlet, pressure drops of one and two percent of the absolute compressor discharge pressure have been assumed for the actual non-regenerative and regenerative cycles, respectively. A pressure drop of 0.3 psi has been assumed on the gas side of the heat exchangers in the actual regenerative cycles. The air temperature at the compressor intake is assumed as 60 F. The calculations employ the temperature-entropy, enthalpy-entropy chart of Fig. 21 and are, therefore, based on variable specific heats. A heat exchanger with a surface of 10 sq ft per hp is used for the actual regenerative cycles having a heat exchanger of finite surface. An overall heat transfer coefficient from gas to air of 10 Btu per hr per sq ft per deg F has been employed.

Curve G shows a peak thermal efficiency of 16.7 percent at a pressure ratio of 4.5 for an actual non-generative cycle operating with a turbine admission temperature of 1000 F. By the addition of a heat exchanger having a surface of 10 sq ft per excess hp, the thermal efficiency for the same turbine temperature may be increased to 24.2 percent at a pressure ratio of 2.5, as shown by curve H. If a heat exchanger of infinite surface is assumed, the thermal efficiency for the 1000 F cycle will be in accordance with curve I. It will be noted that, at the higher pressure ratios, regeneration depreciates rather than enhances the thermal efficiency for any given turbine inlet temperature.

A thermal efficiency as high as 26.8 percent is obtainable with a pressure ratio of 12 in an actual 1500 F non-regenerative cycle, as shown by curve F. Curve E shows that the incorporation of a finite surface heat exchanger will raise the efficiency to 40 percent at a pressure ratio of 3.5. If an infinite surface heat exchanger is assumed, the 1500 F cycle will yield the thermal efficiencies shown by curve D.

The curves discussed in the preceding two paragraphs have involved cycles in which actual losses have been taken into account. Curve B, however, gives thermal efficiencies for a theoretical cycle operating on a non-regenerative cycle with no losses. The efficiency of such a cycle is independent of temperature, being solely a function of pressure ratio, as may be demonstrated by the following procedure.

Thermal efficiency, the ratio of the excess power in heat units to the heat supplied by the fuel, may be expressed as

$$\varepsilon = \frac{\frac{1}{778}\,\frac{k}{k-1}\,R\,(T_C - T_B)\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right]}{c_p\,(T_C - T_B)} \qquad \ldots\ldots(22)$$

where: ε = thermal efficiency, and the other terms

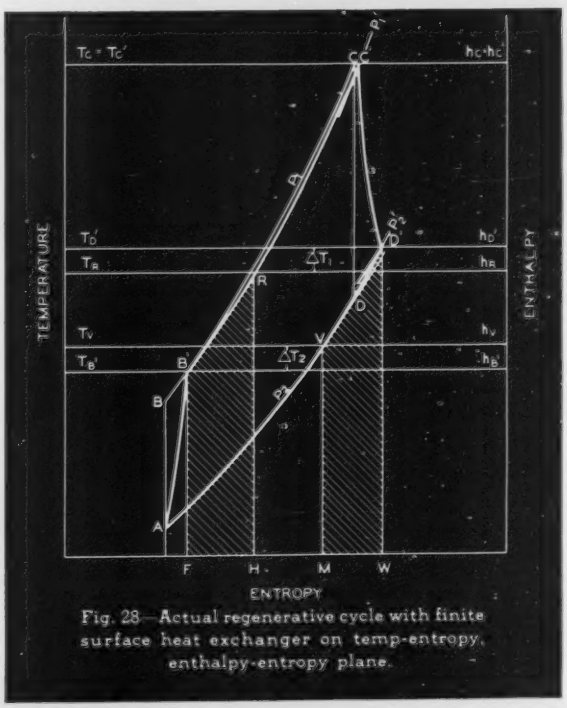


Fig. 28—Actual regenerative cycle with finite surface heat exchanger on temp-entropy, enthalpy-entropy plane.

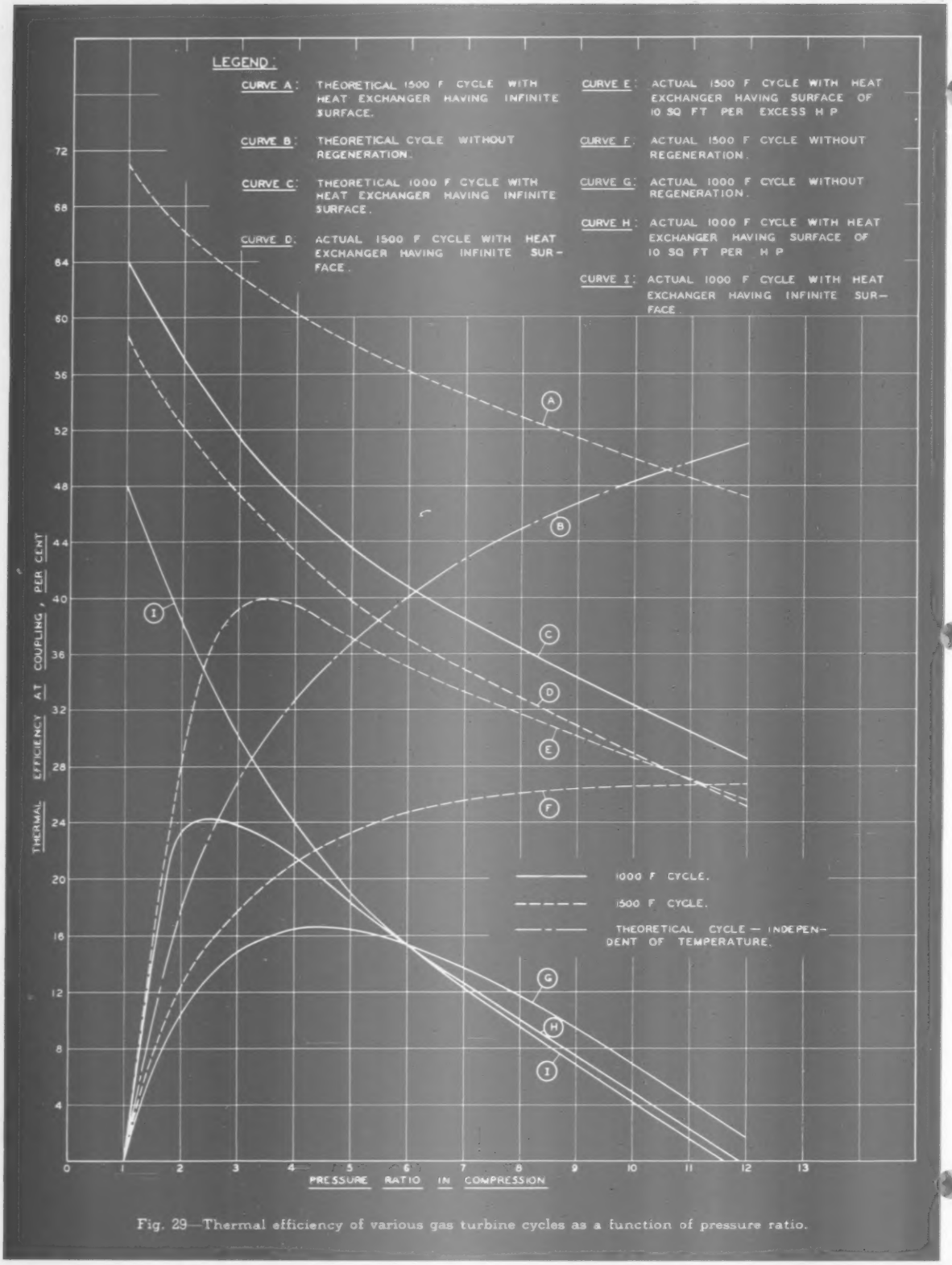


Fig. 29—Thermal efficiency of various gas turbine cycles as a function of pressure ratio.

have the same meaning as when used heretofore. The increase in quantity of fluid caused by the addition of fuel has been neglected in this theoretical cycle.

Using the relation

$$c_p = \frac{R}{778}\left(\frac{k}{k-1}\right) \quad \ldots\ldots\ldots\ldots\ldots (23)$$

equation (22) may be reduced to the form

$$\varepsilon = \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] \quad \ldots\ldots\ldots (24)$$

which shows the thermal efficiency to depend only on pressure ratio. Curve B is a plot of equation (24).

In a theoretical regenerative cycle employing a heat exchanger having infinite surface, the thermal efficiency for unity pressure ratio will be the same as that of the Carnot cycle, as may be shown by the following demonstration.

For a theoretical cycle with ideal regeneration, the air discharged from the compressor will have its temperature raised in the heat exchanger to that of the gas at the turbine exhaust, as shown in Fig. 26. Neglecting the addition of fuel, the thermal efficiency of such a cycle may be expressed as

$$\varepsilon = \frac{\frac{1}{778}\,\frac{k}{k-1} R\,(T_C - T_B)\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right]}{c_p\,(T_C - T_D)} \quad \ldots\ldots (25)$$

Substituting for T_D its value

$$T_D = T_C\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \quad \ldots\ldots\ldots\ldots (26)$$

equation (25) becomes

$$\varepsilon = 1 - \frac{T_B}{T_C} \quad \ldots\ldots\ldots\ldots\ldots\ldots (27)$$

For T_B its value,

$$T_B = T_A\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} \quad \ldots\ldots\ldots\ldots (28)$$

may be substituted and equation (27) becomes

$$\varepsilon = 1 - \frac{T_A}{T_C}\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} \quad \ldots\ldots (29)$$

which approaches the Carnot efficiency with decreasing pressure ratios and is equal to it in the limiting case of unity pressure ratio.

When modified to include actual values of turbine and compressor efficiencies, it can be shown that equation (29) will become

$$\varepsilon = 1 - \frac{1}{\varepsilon_T\,\varepsilon_C}\,\frac{T_A}{T_C}\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} \quad \ldots (30)$$

where: ε_T = turbine efficiency

ε_C = compressor efficiency.

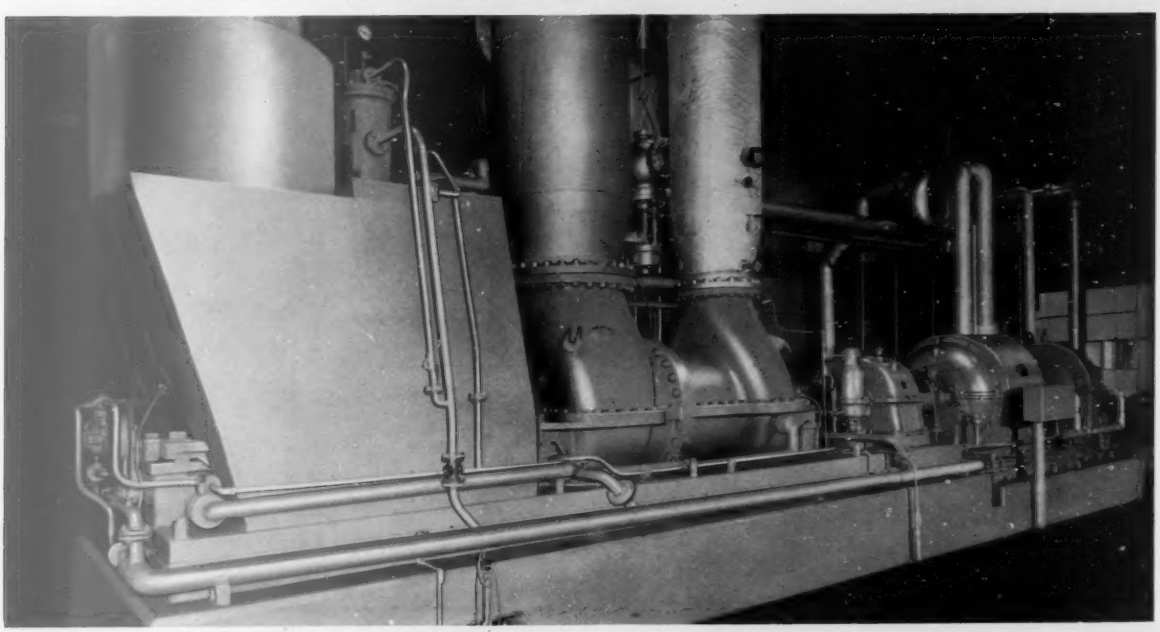
Thermal efficiencies of theoretical 1500 F and 1000 F regenerative cycles are given by curves A and C, respectively, which include correction for the addition of fuel.

Examination of Fig. 29 will reveal the desirability of employing elevated temperatures as well as regeneration in order to achieve high thermal efficiency in the gas turbine cycle.

Applications

As mentioned previously, the combustion gas turbine in the United States has had its principal commercial

Fig. 30 — The largest Houdry unit yet in service — rated 60,000 cfm — aids production of high octane gasoline.



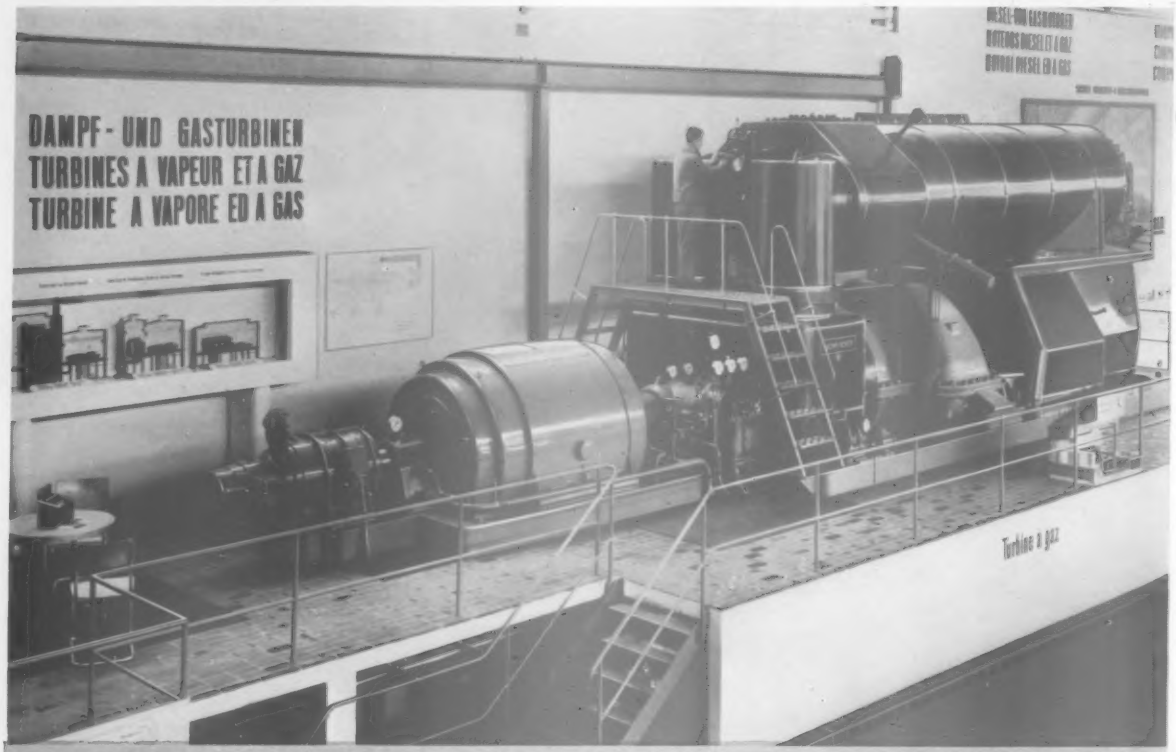
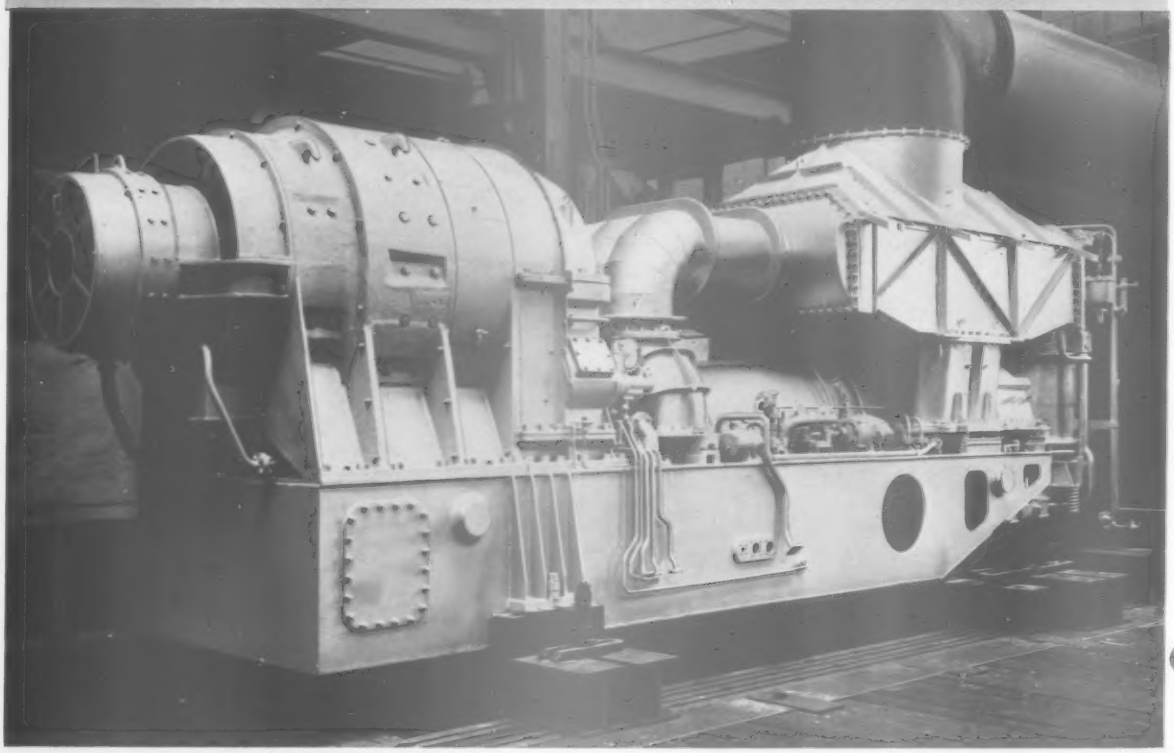


Fig. 31 — The first modern combustion gas turbine designed primarily for producing power — a 4000 kw electric generating unit.

Fig. 32 — A 2200 hp gas turbine power unit for an electric locomotive for the Swiss Federated Railways.



application in the oil refinery industry, where it operates in conjunction with the Houdry process. A typical installation view of a Houdry application employing a 60,000 cfm unit is shown in Fig. 30, wherein, from left to right, may be seen the gas turbine, axial compressor, reduction gear, generator, and a steam turbine for starting purposes. In this application, due to the pressure drop encountered in the process, the energy supplied to the generator is less than if the unit were used primarily for purposes of power production.

The first unit of this type has been in continuous service since December, 1936. At present 17 of the Houdry units are in operation in this country, and three are now being built by Allis-Chalmers.

A 4000 kw electric generating unit[12] designed and built by Brown-Boveri has been installed in an underground emergency standby power station in the City of Neuchâtel, Switzerland. Since early in 1940 this unit has been operating for certain periods every week. Its simplicity and independence of water facilities ideally adapt the gas turbine to this class of service. As recounted heretofore, recently published tests indicate a coupling thermal efficiency of 18.04 percent for this unit when operating on a non-regenerative cycle with a turbine inlet temperature of 1000 F. Regeneration was not adopted since it could not be economically justified because of the anticipated intermittent operation associated with this particular installation. This is the first unit designed for the primary purpose of producing power. The Neuchâtel unit on exhibition at the Swiss National Exposition at Zurich is shown in Fig. 31.

About 80 gas turbine-axial compressor sets have been built by Brown-Boveri to operate in conjunction with the Velox boiler, a pressure-combustion type where the axial compressor furnishes air at a pressure of 30 to 35 psi gauge to the combustion chamber and the resulting products of combustion actuate the gas turbine; and hundreds are used for supercharging Diesel engines.

Figure 32 shows a shop view of a 2200 hp gas turbine power unit for a gas turbine-electric locomotive built by Brown-Boveri for the Swiss Federal Railways. The completed locomotive, operating on a regenerative cycle with a d-c transmission, is reported to have undergone trial runs during the latter part of 1941. Exact data regarding the locomotive are not available at this writing, but it is understood that it has a maximum speed of about 80 mph and weighs approximately 108 lb per rail hp exclusive of fuel.

An engineering study of the possibilities of the gas turbine as a drive for locomotives of larger output is being conducted in this country by Allis-Chalmers[13]. Various arrangements have been considered including electrical and hydro-mechanical transmissions. An arrangement diagram of a 5000 hp, hydraulic transmission, locomotive weighing 112 lb per rail hp and capable of speeds up to 120 mph is shown in Fig. 33.

In the interest of weight reduction and also to achieve more uniform distribution of weight, the power plant has been divided into two units of 2500

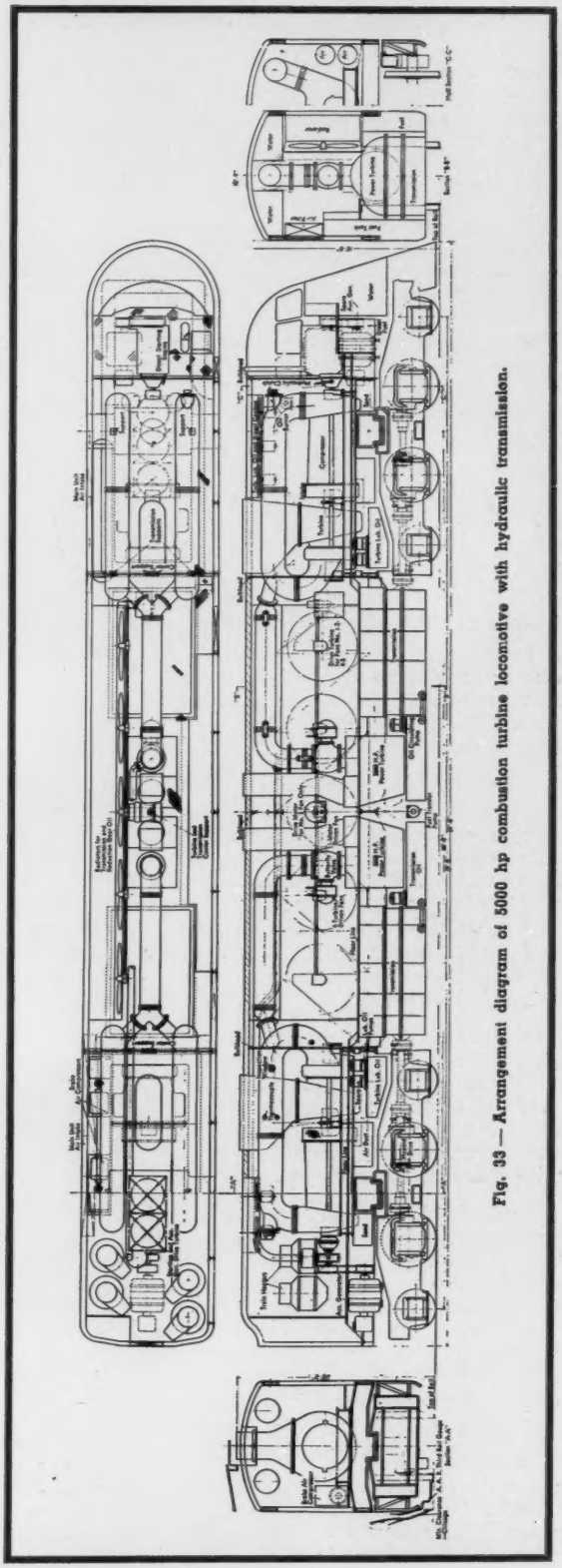


Fig. 33 — Arrangement diagram of 5000 hp combustion turbine locomotive with hydraulic transmission.

(13) J. L. Ray, "An Engineering Study of the Combustion Turbine Locomotive," Allis-Chalmers Bulletin B6066, Sept. 6, 1939.

hp each. In each unit a two-turbine design has been adopted — one turbine furnishes sufficient power to drive the compressor only, and the excess gas generated operates the other turbine, thereby providing propulsive power to the locomotive. The use of separate turbines improves the partial load performance since the compressor and its driving turbine can operate independently at their optimum speed regardless of the speed of the locomotive.

The hydro-mechanical transmission, consisting of a torque converter and hydraulic coupling for low and high speeds, respectively, affords a high tractive effort at starting without a sacrifice in maximum speed. Control of the locomotive speed is accomplished by a combination of manual and governor regulation of the fuel burned in the combustion chamber and also by throttling the gas supplied to the power turbine.

It is expected that numerous other favorable applications of the gas turbine will develop periodically and will probably include marine propulsion, blast furnace plants, wind tunnels, remotely located power plants, oil fields having an abundance of natural gas but a scarcity of water, and other special applications.

Conclusions

A recapitulation of the material herein presented indicates that the future of the gas turbine becomes more promising with the adoption of higher temperatures. Continued metallurgical advances and effective cooling methods bring operation at elevated temperatures ever closer to the realm of practicability.

Field experience with the units already in operation indicates their design to be conservative, and no troubles attributable to operating temperatures have been encountered. Based upon this experience, as well as that of supercharger work, it is believed that operation at temperatures higher than those now in use is entirely feasible and that it can be accomplished with an adequate margin of safety.

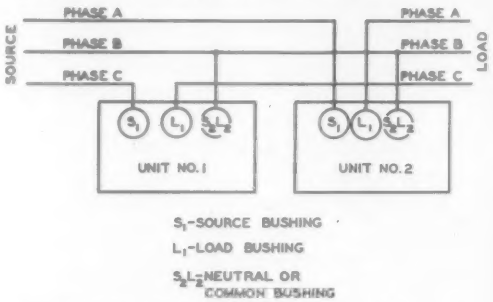
Improvement in thermal efficiency, made possible by the use of regeneration and increased temperatures, makes the gas turbine a serious aspirant as a prime mover for certain applications. Because of the low grade of fuel it can use, the gas turbine, even when operating at present temperature levels without regeneration, compares favorably on a fuel cost basis with other methods of power production.

Undoubtedly the gas turbine has certain natural applications which make the cycle appear attractive. The advantages associated with the elimination of the high pressure, high temperature steam boilers, and the attendant feedwater problems from a power plant are obvious. At present the cycle is only applicable where liquid or gaseous fuels can be used although research has shown some promise for the application of pulverized fuel for this service.

The gas turbine is not regarded as the answer to all power problems since its limitations are well recognized. It is believed, however, that it possesses definite features which ideally adapt it for certain classes of service; and it is toward this end that the present development is being directed.

Question—How may I connect two single-phase, 2400 volt regulators on a 2400 volt ungrounded system?—A. D. R.

Answer—Two regulators may be connected in open-delta on an ungrounded system as shown in the diagram below. With this connection, the two regulators respond to the regulation requirements of two of the phases, and the third phase receives the average regulation of the other two phases.



Question—We have a machine-tool application requiring a 7½ hp, 870/1700 rpm, open type, direct-current motor. The machine will operate at rated output at low speed a maximum of only about three hours at a time. A frame size smaller than standard is desirable because of space limitations. How can we get a smaller motor?—S. R.

Answer—No reduction in frame size is possible on the basis of three-hour intermittent operation because a small motor like this one will come up to temperature within that period of time.

Standard Class A insulation will stand a maximum temperature of 90 C; and, if the motor is operated at a higher temperature, the insulation could not be guaranteed for a normal life. A standard d-c motor is so rated that the maximum temperature rise will be 40 C in a 50 deg ambient. On the other hand, with Class B insulation a frame size smaller than standard can be used, providing a temperature rise of 70 C is not objectionable. A Class B insulated motor, however, would cost more than a standard Class A insulated machine.

Further reduction in frame size could be obtained only if the machine tool could be designed to utilize a higher-speed motor.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

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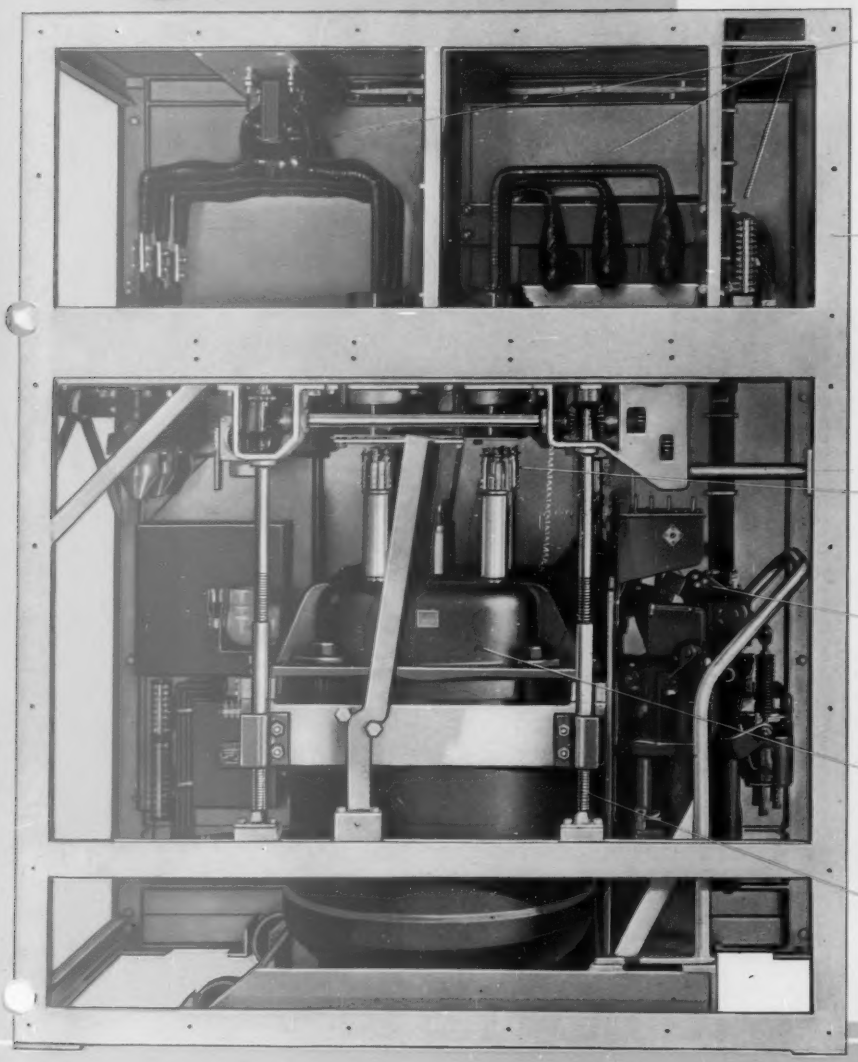

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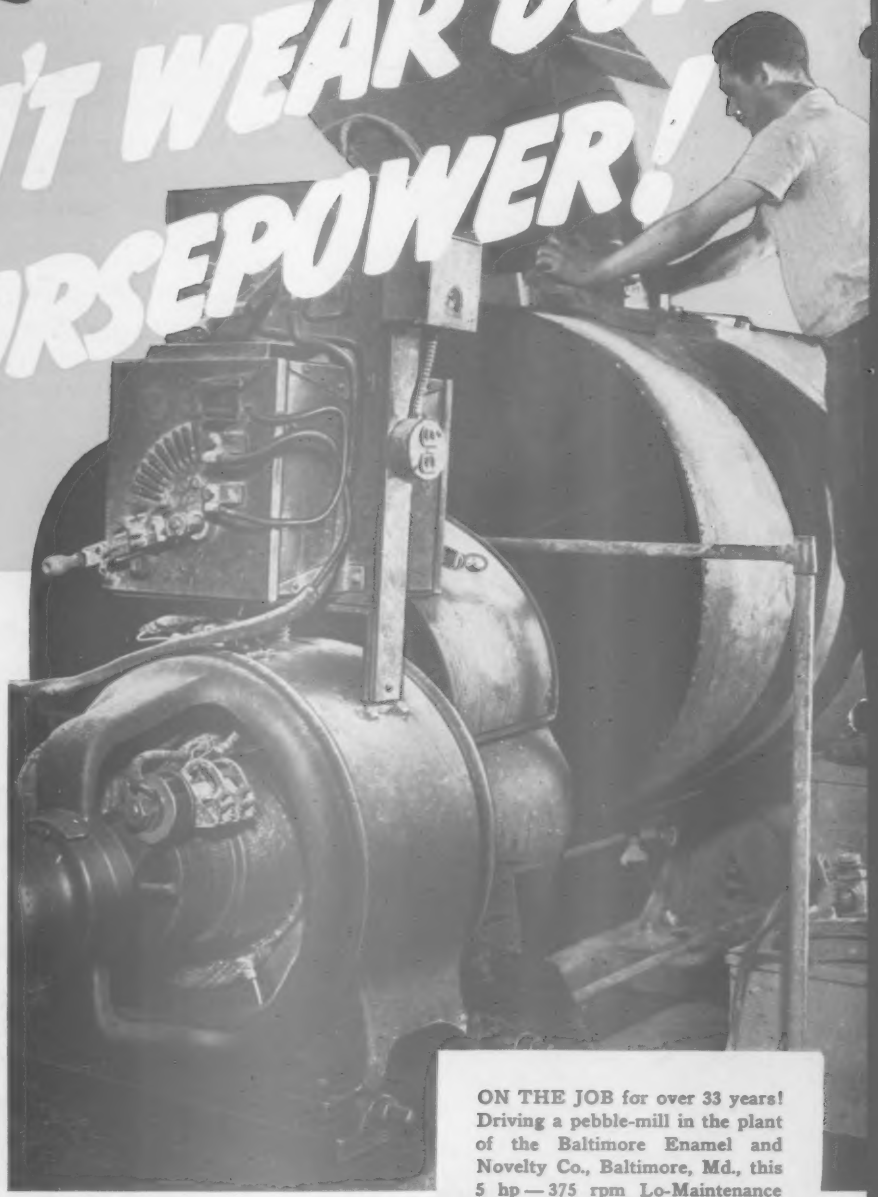

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